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FOR: LIGHT SOURCE UNIT AND   :
WAVELENGTH STABILIZING CONTROL
METHOD, EXPOSURE APPARATUS AND
EXPOSURE METHOD, METHOD OF
MAKING EXPOSURE APPARATUS, AND
DEVICE MANUFACTURING METHOD
AND DEVICE

SUBMISSION OF CERTIFIED ENGLISH TRANSLATION

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SIR:

Applicants submit herewith Certification of Translations and Certified English

Translations of five foreign priority documents (Japanese Patent Application No. 11-257969,

Japanese Patent Application No. 11-258089, Japanese Patent Application No. 11-259615,

Japanese Patent Application No. 2000-153320, and Japanese Patent Application No. 2000-

190826).

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Certification of Translation

(Japanese Patent Application No. 11-257,969)

I, the undersigned, Sawako KODAMA residing at 1-25-5-204, Yutenji, Meguro-ku, Tokyo 153-0052, JAPAN do solemnly and sincerely declare that I am well acquainted with the Japanese language and the English language and that the attached English translation of the Japanese Patent Application No. 11-257,969 filed September 10, 1999 is an accurate translation to the best of my knowledge and belief from the Japanese language into the English language.

Date: March 9, 2006

Sawako Kodama

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[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION]

LIGHT SOURCE UNIT, EXPOSURE APPARATUS AND EXPOSURE METHOD, AND DEVICE MANUFACTURING METHOD

5   [CLAIMS]

[CLAIM 1] A light source unit that generates light with a single wavelength, said light source unit comprising:

a light generating portion which generates light with 10 a single wavelength;

a fiber group made up of a plurality of optical fibers arranged in parallel on an output side of said light generating portion; and

a light amount control unit which controls light 15 amount emitted from said optical fiber group by individually turning on/off light output from each optical fiber of said optical fiber group.

[CLAIM 2] The light source unit according to Claim 1, wherein at least an output end of each of said plurality 20 of optical fibers making up said fiber group is bundled so as to structure a bundle-fiber.

[CLAIM 3] The light source unit according to one of Claims 1 and 2, wherein

at least one stage of a fiber amplifier that can 25 perform optical amplification is arranged on a part of each optical path, which is structured including said each optical fiber, and

said light amount control unit performs on/off operation of said light output from said each optical fiber by switching intensity of pumped light from a pumping light source of said fiber amplifier.

5   [CLAIM 4] The light source unit according to Claim 3, wherein said light amount control unit performs said switching of pumped light intensity by selectively setting intensity of pumped light from said pumping light source to one of a predetermined level and a zero level.

10   [CLAIM 5] The light source unit according to Claim 4, wherein said light amount control unit selectively sets said intensity of pumped light from said pumping light source to one of said predetermined level and said zero level by performing on/off operation on said pumping

15   light source.

[CLAIM 6] The light source unit according to Claim 3, wherein said light amount control unit performs said intensity switching of said pumped light by selectively setting said pumped light intensity from said pumping

20   light source to one of a predetermined first level and a second level smaller than said first level.

[CLAIM 7] The light source unit according to any one of Claims 3 to 6, wherein

said each optical path has a plurality of said fiber

25   amplifiers arranged, and

said light amount control unit performs on/off operation of said light output from said each optical

fiber by switching intensity of pumped light from a pumping light source of a fiber amplifier arranged at a final stage.

[CLAIM 8] The light source unit according to Claim 7,
5 wherein a mode field diameter of said fiber amplifier arranged most downstream directly before said light output is large, when compared with other fiber amplifiers arranged before said fiber amplifier.

[CLAIM 9] The light source unit according to any on
10 of Claims 1 to 8, said light source further comprising:

a memory unit which has an output intensity map corresponding to an on/off state of light output from said each optical fiber stored in advance, and

said light amount control unit individually turns
15 on/off light output from said each optical fiber based on said output intensity map and a predetermined set light amount.

[CLAIM 10] The light source unit according to Claim 9, wherein said output intensity map is made based on
20 dispersion of light output from said each optical fiber measured in advance.

[CLAIM 11] The light source unit according to any one of Claims 1 to 8, said light source further comprising:

a wavelength conversion portion which converts a
25 wavelength of said light output from said each optical fiber.

[CLAIM 12] The light source unit according to one of

Claims 9 and 10, said light source further comprising:

a wavelength conversion portion which converts a wavelength of said light output from said each optical fiber; and

5 said output intensity map is made with further consideration on light output dispersion due to dispersion in wavelength conversion efficiency, which corresponds to light output from said each optical fiber measured in advance.

10 **[CLAIM 13]** The light source unit according to any one of Claims 1 to 12, wherein

said light generating portion includes a light source which generates light having a single wavelength and an optical modulator which converts said light from said

15 light source into a pulse light having a predetermined frequency and emits said pulse light, and

said light amount control unit further controls at least one of a frequency and a peak power of said pulse light emitted from said optical modulator.

20 **[CLAIM 14]** The light source unit according to any one of Claims 1 to 13, said light source unit further comprising a delay portion, which individually delays light output from said plurality of optical fibers respectively so as to stagger said light output

25 temporally.

[CLAIM 15] A light source unit that generates light with a single wavelength, said light source unit

comprising:

a light generating portion that has a light source which generates light with a single wavelength and an optical modulator which converts light from said light

5   source into a pulse light with a predetermined frequency and emits said pulse light;

a light amplifying portion which includes at least one fiber amplifier to amplify said pulse light generated by said light generating portion; and

10   a light amount control unit which controls light amount of light output from said fiber amplifier by controlling a frequency of said pulse light emitted from said optical modulator.

[CLAIM 16] The light source unit according to Claim

15   15, said light source unit further comprising:

a memory unit which has an output intensity map of said light amplifying portion corresponding to a frequency of said pulse light entering said light amplifying portion stored, and

20   said light amount control unit controls said frequency of said pulse light emitted from said optical modulator based on said output intensity map and a predetermined set light amount.

[CLAIM 17] The light source unit according to one of

25   Claims 15 and 16, wherein said light amount control unit further controls a peak power of said pulse light emitted from said optical modulator.

[CLAIM 18] The light source unit according to one of Claims 15 and 16, wherein

said optical modulator is an electrooptical modulator, and

5   said light amount control unit controls said frequency of said pulse light by controlling a frequency of voltage pulse impressed on said optical modulator.

[CLAIM 19] A light source unit that generates light with a single wavelength, said light source comprising:

10   a light generating portion that has a light source which generates light with a single wavelength and an optical modulator which converts light from said light source into a pulse light with a predetermined frequency and emits said pulse light;

15   a light amplifying portion which includes at least one fiber amplifier to amplify said pulse light generated by said light generating portion; and

a light amount control unit which controls light amount of light output from said amplifying portion by

20   controlling a peak power of said pulse light emitted from said optical modulator.

[CLAIM 20] The light source unit according to Claim 19, said light source unit further comprising:

a memory unit which has an output intensity map of

25   said light amplifying portion corresponding to intensity of said pulse light entering said light amplifying portion stored, and

said light amount control unit controls a peak power of said pulse light emitted from said optical modulator based on said output intensity map and a predetermined set light amount.

5   [CLAIM 21] The light source unit according to one of Claims 19 and 20, wherein

said optical modulator is an electrooptical modulator, and

said light amount control unit controls said peak 10   power of said pulse light by controlling a peak level of voltage pulse impressed on said optical modulator.

[CLAIM 22] The light source unit according to any one of Claims 15 to 21, wherein

said light amplifying portion is arranged in plural 15   and in parallel, and

an output end of each said light amplifying portion is each made up of an optical fiber.

[CLAIM 23] The light source unit according to Claim 22, wherein a plurality of said optical fibers that 20   respectively make up a plurality of said light amplifying portions are bundled so as to structure a bundle-fiber.

[CLAIM 24] The light source unit according to any one of Claims 15 to 23, said light source unit further comprising a wavelength conversion portion, which 25   converts a wavelength of light emitted from said light amplifying portion.

[CLAIM 25] The light source unit according to one of

Claims 22 and 23, said light source unit further comprising a delay portion, which individually delays light output from said plurality of light amplifying portions respectively so as to stagger said light output

5 temporally.

[CLAIM 26] The light source unit according to any one of Claims 11, 12 and 24, wherein

said light generating portion generates a single wavelength laser beam within a range of infrared to

10 visible region, and

said wavelength conversion portion emits ultraviolet light which is a harmonic wave of said single wavelength laser beam.

[CLAIM 27] The light source unit according to Claim

15 26, wherein

said light generating portion generates a single wavelength laser beam that has a wavelength of around 1.5µm, and

said wavelength conversion portion generates one of

20 an eighth-harmonic wave and a tenth-harmonic wave of said single wavelength laser beam having said wavelength of around 1.5µm.

[CLAIM 28] An exposure apparatus that transfers a pattern formed on a mask onto a substrate, said exposure

25 apparatus comprising:

the light source unit according to one of Claims 26 and 27; and

an illumination optical system that illuminates said mask with light emitted from said light source unit as an illumination light for exposure.

[CLAIM 29] The exposure apparatus according to Claim 28, wherein within said illumination optical system an optical integrator that uniforms a distribution of illumination light on a pattern surface of said mask.

[CLAIM 30] The exposure apparatus according to one of Claims 28 and 29, wherein said illumination optical system is a Koehler illumination system.

[CLAIM 31] An exposure apparatus that repeatedly transfers a pattern formed on a mask onto a substrate, said exposure apparatus comprising:

a light generating portion that has a light source which generates light with a single wavelength and an optical modulator which converts light from said light source into a pulse light;

a light amplifying portion which includes at least one fiber amplifier to amplify a pulse light generated in said light generating portion;

a control unit which controls at least one of a frequency and a peak power of said pulse light via said optical modulator in accordance with a position of an area subject to exposure on said substrate, when said substrate is exposed via said mask by irradiating said amplified pulse light on said mask.

[CLAIM 32] An exposure apparatus that transfers a

pattern formed on a mask onto a substrate, said exposure apparatus comprising:

   a light generating portion that has a light source which generates light with a single wavelength and an optical modulator which converts light from said light source into a pulse light;

   a light amplifying portion made up of a plurality of optical paths arranged in parallel on an output side of said light generating portion, said optical paths including at least one fiber amplifier to amplify said pulse light; and

   a control unit which controls light amount of said pulse light emitted from said light amplifying portion by individually turning on/off light output from said plurality of optical paths respectively, when said substrate is exposed via said mask by irradiating said pulse light emitted from said light amplifying portion on said mask.

   [CLAIM 33] The exposure apparatus according to one of Claims 31 and 32, wherein

   said light source generates a laser beam in one of an infrared and a visible region, and said exposure apparatus further comprises:

   a wavelength conversion portion which converts a wavelength of said pulse light amplified in said light amplifying portion into a wavelength of ultraviolet light.

   [CLAIM 34] An exposure method that repeatedly

transfers a pattern formed on a mask onto a substrate, said exposure method including:

a first step of amplifying a pulse light using a fiber amplifier at least once;

a second step of exposing an area subject to exposure on said substrate via said mask by irradiating said amplified pulse light onto said mask; and

a third step of converting a laser beam emitted from a light source to said pulse light and controlling at least one of a frequency and a peak power of said pulse light in accordance with a position of said area subject to exposure on said substrate, prior to said first step.

[CLAIM 35] The exposure method according to Claim 34, wherein

said fiber amplifier is arranged in plural and in parallel, and

in said first step, said pulse light is amplified by using only selected fiber amplifiers.

[CLAIM 36] The exposure method according to one of Claims 34 and 35, wherein

said light source generates a laser beam in one of an infrared and a visible region, and said exposure method further includes:

a fourth step of performing wavelength conversion on said amplified pulse light for conversion into an ultraviolet light before said pulse light is irradiated on said mask.

[CLAIM 37] A device manufacturing method including a photolithographic process, wherein exposure is performed using said exposure apparatus according to any one of Claims 28 to 33 in said photolithographic process.

5   **[CLAIM 38]** A device manufacturing method including a photolithographic process, wherein said exposure method according to any one of Claims 34 to 36 is used in said photolithographic process.

[CLAIM 39] A device manufactured using said device

10   manufacturing method according to one of Claims 37 and 38.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[RELEVANT TECHNICAL FIELD TO THE INVENTION]

15   The present invention relates to a light source unit, an exposure apparatus and an exposure method, and a device and device manufacturing method. More particularly, the present invention relates to a suitable light source unit which serves as a light source for exposure in an

20   exposure apparatus to manufacture a semiconductor device and a liquid crystal display device and the like in a lithographic process, an exposure apparatus which comprises the light source unit as a light source for exposure, an exposure method using the exposure apparatus,

25   and a device manufacturing method using the exposure apparatus and the exposure method and a device manufactured by the device manufacturing method.

[0002]

[RELATED ART]

Conventionally, in the lithographic process to manufacture a semiconductor device (integrated circuit), a liquid crystal display device, and the like, various exposure apparatus were used. In recent years, as these types of exposure apparatus, the reduction projection exposure apparatus such as the so-called stepper or the so-called scanning stepper is mainstream, from the viewpoint of having high throughput. With the reduction projection exposure apparatus, a fine circuit pattern formed on a photomask or a reticle is reduced, projected, and transferred onto a substrate such as a wafer or a glass plate, which surface is coated with a photoresist via a projection optical system.

[0003]

However, the exposure apparatus such as the projection exposure apparatus require high resolution, along with high throughput. The resolution R, and the depth of focus DOF of the projection exposure apparatus are respectively expressed in the following equation (1) and (2), using the wavelength of the illumination light for exposure λ and the numerical aperture of the projection optical system N.A.:

[0004]

$$R = K \cdot \lambda \, / \, N.A. \qquad \cdots \cdots (1)$$

[0005]

$$DOF = \lambda / 2 \ (N.A.)^2 \qquad \cdots \cdots (2)$$

[0006]

As is obvious from equation (1), three ways can be considered to obtain a smaller resolution R, that is, to decrease the minimum pattern line width that can be resolved; ① reduce the proportional constant K, ② increase the N.A., ③ reduce the wavelength of the illumination light for exposure λ. The proportional constant K, in this case, is a constant that is determined by the projection optical system or the process, and is normally a value around 0.5 to 0.8. The method of decreasing the constant K is called super-resolution in a broad sense. Up until now, issues such as improvement of the projection optical system, modified illumination, phase shift reticle have been studied and proposed, however, there were drawbacks such as the patterns suitable for application being restricted.

[0007]

On the other hand, as can be seen from equation (1), the resolution R can be reduced by increasing the numerical aperture N.A., however, at the same time, this means that the depth of focus DOF is small, as is obvious from equation (2). Therefore, increasing the N.A. value has its limits, and normally, the appropriate value is around 0.5 to 0.6.

[0008]

Accordingly, the most simple and effective way of

reducing the resolution R is to reduce the wavelength of the illumination light for exposure λ.

[0009]

For such reasons, conventionally, the g-line stepper and the i-line stepper that use an ultra-high pressure mercury lamp as the light source for exposure to emit the emission line (such as the g line or the i line) in the ultraviolet light region were mainly used, as the stepper or the like. However, in recent years, the KrF excimer laser stepper that uses a KrF excimer laser as the light source to emit a KrF excimer laser beam having a shorter wavelength (wavelength: 248nm) is becoming mainstream. And currently, the exposure apparatus that uses the ArF excimer laser (wavelength: 193nm) as the light source having a shorter wavelength is under development.

[0010]

[PROBLEMS TO BE RESOLVED BY THE INVENTION]

The excimer laser, however, has disadvantages as the light source for the exposure apparatus, such as, the size being large, the energy per pulse being large causing the optical components to damage easily, and the maintenance of the laser being complicated and expensive because of using poisonous fluorine gas.

[0011]

Also, the exposure apparatus will be expected to achieve exposure amount control performance in line with the difference of the resist sensibility in each wafer,

and a wide dynamic range, typically around 1 to 1/7, will be required. With the exposure apparatus using the conventional excimer laser as the light source, for example, the rough energy adjuster such as the ND filter

5 is used for exposure amount control in accordance with the difference of the resist sensibility in each wafer.

[0012]

In the case of such a method, however, an ND filter with a calibrated transmittance was required, and the

10 durability of the ND filter and the change in transmittance with the elapse of time caused a problem. Furthermore, even in the case when only 1/7 of the maximum exposure light amount was required, the excimer laser operated to emit the exposure light at the maximum

15 intensity, therefore, 6/7 of the emitted light was not used upon exposure, and was wasted. And, there were also difficulties on points such as the optical components wearing out and power consumption.

[0013]

20 With the current exposure apparatus, other than the exposure amount control performance in accordance with the difference of the resist sensibility in each wafer (hereinafter referred to as the "first exposure amount control performance" as appropriate), the exposure amount

25 control performance to correct the process variation of each shot area (chip) on the same wafer (hereinafter referred to as the "second exposure amount control

performance" as appropriate) is required. Also, in the case of the scanning stepper, the exposure amount control performance to achieve line width uniformity within the shot area (hereinafter referred to as the "third exposure

5   amount control performance" as appropriate) is further required.

[0014]

With the current exposure apparatus, as the second exposure amount control performance referred to above,

10   the dynamic range is required to be around ±10% of the exposure amount set, the exposure amount is required to be controlled within about 100ms, which is the stepping time in between shots, to a value set, and the control accuracy is required to be around ±1% of the exposure

15   amount set.

[0015]

And, as the third exposure amount control performance referred to above, the control accuracy is required to be set at ±0.2% of the exposure amount set within 20ms,

20   which is the typical exposure time on one shot area, with the control velocity around 1ms.

[0016]

Accordingly, as the light source of the exposure apparatus, in order to achieve the first to third

25   exposure amount control performance described above, the advent of a light source unit that can perform control corresponding to necessary requirements for control is

highly expected. Control corresponding to necessary requirements for control, here, refers to functions such as (a) dynamic range of control, (b) control accuracy, (c) control velocity, (d) degree of linearity between the detected light intensity and the control amount, and (e) energy saving functions for the purpose of power-saving.

[0017]

The present invention has been made in consideration of the situation described above, and has as its first object to provide a light source unit that can perform light amount control corresponding to necessary requirements for control described above.

[0018]

It is the second object of the present invention to provide an exposure method that can easily achieve the exposure amount control required.

[0019]

And, it is the third object of the present invention to provide a device manufacturing method that can improve the productivity of the microdevice with high integration.

[0020]

[MEANS FOR SOLVING THE PROBLEMS]

The invention according to Claim 1 is a light source unit that generates light with a single wavelength, the light source unit comprising: a light generating portion (160) which generates light with a single wavelength; a fiber group made up of a plurality of optical fibers

arranged in parallel on an output side of the light generating portion; and a light amount control unit (16C) which controls light amount emitted from the optical fiber group by individually turning on/off light output

5   from each optical fiber of the optical fiber group.

[0021]

With the light source unit, light with a single wavelength generated in the light generating portion proceeds toward the plurality of optical fibers that

10   respectively structure the fiber group arranged in parallel on the output side of the light generating portion, while the light amount control unit controls the light amount emitted from the optical fiber group by individually turning on/off light output from each

15   optical fiber of the optical fiber group. As is described, in the present invention, the amount of light emitted from the fiber group can be controlled by a simple method of individually turning on/off the light output from each optical fiber making up the optical fiber group, and also,

20   light amount control in multiple stages, which is proportional to the number of optical fibers, becomes possible. Therefore, a wide dynamic range can be achieved. In this case, various performances (including the fiber diameter) of each optical fiber may differ, however, in

25   the case the performance is almost the same in each optical fiber, since the same amount of light can be emitted from each optical fiber, an accurate and reliable

light amount control in N stages in accordance with the number of optical fibers N can be performed. Accordingly, for example, if N >=100, then the light amount can be controlled with the precision of 1% and under. In this

5   case, the degree of linearity between the controlled amount and the light amount is favorable. Of course, in this case, the rough energy adjuster such as the ND filter will not be necessary, therefore, problems such as deterioration in light amount control performance due to

10 the durability of the filter or the temporal change in transmittance can be improved.

[0022]

In this case, as in the invention according to Claim 2, at least an output end of each of the plurality of

15 optical fibers making up the fiber group may be bundled so as to structure a bundle-fiber (173). In general, since the diameter of the optical fiber is narrow, even when a hundred fibers and over are bundled, the diameter of the bundle is within a few mm, thus allowing a compact

20 optical element to be arranged in the case when an optical element of some kind is arranged on the output side of the bundle fiber.

[0023]

With the light source unit related to each invention

25 according to Claims 1 and 2, various methods can be considered of turning on/off the light output from each optical fiber, such as arranging a mechanical or an

electrical shutter to cut off the light incident on each optical fiber, or arranging a mechanical or an electrical shutter so as to prevent the light from being emitted from each optical fiber. Or, for example, as in the

5   invention according to Claim 3, in the case at least one stage of a fiber amplifier (168_n, 171_n) that can perform optical amplification is arranged on a part of each optical path (172_n), which is structured including each optical fiber, then the light amount control unit may

10   perform on/off operation of the light output from each optical fiber by switching the intensity of pumped light from a pumping light source (174, 178) of the fiber amplifier.

[0024]

15   "At least one stage of a fiber amplifier that can perform optical amplification is arranged on a part of each optical path, which is structured including each optical fiber," here, includes both cases, when each optical path has an optical amplifying unit arranged

20   separately on the input side of the optical fiber and when a part of the optical fiber structuring each optical path is a fiber amplifier.

[0025]

In such cases, since the light incident on the

25   optical path including each optical fiber can be amplified by the fiber amplifier, and the intensity level of the pumped light supplied to the optical amplifying

unit arranged on the optical path including the optical fiber which output has been decided to be turned off is set at a low level (including zero), energy saving becomes possible. In addition, since the on/ff operation

5 of the light output is performed by switching the light intensity of the pumped light from the light source for the pumped light of the fiber amplifier, the on/off operation of the light output becomes possible within a shorter period of time, compared with the case of using

10 ·shutters and the like.

[0026]

In this case, the intensity level switching of the pumped light may be performed between two levels that are not fixed within a predetermined range. However, as in

15 the invention according to Claim 4, the light amount control unit may perform the switching of the pumped light intensity by selectively setting the intensity of pumped light from the pumping light source to one of a predetermined level and a zero level. In such a case, as

20 in the invention according to Claim 5, the light amount control unit may selectively set the intensity of pumped light from the pumping light source to one of a predetermined level and the zero level by performing on/off operation on the pumping light source.

25 **[0027]**

In the light source related to the invention according to Claim 3, as in the invention according to

Claim 6, the light amount control unit may perform the intensity switching of the pumped light by selectively setting the pumped light intensity from the pumping light source to one of a predetermined first level and a second

5   level smaller than the first level. That is, with the fiber amplifier, even if the intensity of the pumped light is not zero, if it is under a predetermined amount, the light is absorbed so that the intensity of the emitted light from the fiber amplifier is almost zero.

10   Therefore, by selectively setting the intensity of the pumped light from the pumping light source to either a predetermined first level or to a second level which is smaller than the first level, the light output from the optical fiber can be turned on/off. In this case, as well,

15   the first level and the second level may be of two levels that are not fixed, within a predetermined range.

[0028]

In the light source unit related to each invention according to Claims 3 to 6, as in the invention according

20   to Claim 7, in the case each optical path has a plurality of the fiber amplifiers arranged, the light amount control unit may perform on/off operation of the light output from each optical fiber by switching the intensity of pumped light from a pumping light source of a fiber

25   amplifier (171_n) arranged at a final stage. In such a case, the adverse effect of the ASE (Amplified Spontaneous Emission), which is a problem when switching

the intensity of the pumped light from the pumping light source of fiber amplifiers other than the fiber amplifier arranged most downstream directly before the light output, can be avoided, as well as have a larger effect on energy

5   saving in the pumping light source when the light output from the optical fiber is turned off since the fibers arranged more downstream require a higher intensity of pumped light.

[0029]

10 In this case, as in the invention according to Claim 8, it is preferable for the mode field diameter of the fiber amplifier arranged most downstream directly before the light output to be large, when compared with other fiber amplifiers arranged before the fiber amplifier. In

15 such a case, broadening of the spectral width of the amplified light can be avoided, due to the nonlinear effect in the optical fiber.

[0030]

The light source unit related to each invention

20 according to Claims 1 to 8 may further comprise a memory unit (51) which has an output intensity map corresponding to an on/off state of light output from each optical fiber stored in advance, and the light amount control unit may individually turn on/off light output from each

25 optical fiber based on the output intensity map and a predetermined set light amount. In such a case, even if the output of each optical fiber is dispersed, the light

output of the fiber group can be made to almost coincide with the set light amount, and it also becomes possible to use optical fibers which performance differ.

[0031]

In this case, it is preferable for the output intensity map to be made based on dispersion of light output from each optical fiber measured in advance. In such a case, since the output intensity map is made from actual measurements on dispersion of light output from each optical fiber which are measured in advance, the light output of the fiber group can be made to coincide with the set light amount without fail.

[0032]

The light source unit related to each invention according to Claims 1 to 8, as in the invention according to Claim 11, may further comprise a wavelength conversion portion (163), which converts the wavelength of the light output from each optical fiber. In such a case, the output of the wavelength conversion portion is proportional to the number of the fibers which output is turned on. Therefore, for example, in the case the performance of each fiber is almost the same, then the same light amount can be emitted from each optical fiber, thus the light amount can be controlled with favorable linearity.

[0033]

In the light source unit related to each invention

according to Claims 9 and 10, as in the invention according to Claim 12, in the case the light source further comprises a wavelength conversion portion which converts a wavelength of the light output from each

5 optical fiber; the output intensity map is preferably made with further consideration on light output dispersion due to dispersion in wavelength conversion efficiency, which corresponds to light output from each optical fiber measured in advance. In such a case, even

10 if there is dispersion in wavelength conversion efficiency corresponding to the light output from each optical fiber, the light amount of the light output can be controlled to the set light amount.

[0034]

15 In the light source unit related to each invention according to Claims 1 to 12, as in the invention according to Claim 13, in the case the light generating portion includes a light source (160A) which generates light having a single wavelength and an optical modulator

20 (160C) which converts the light from the light source into a pulse light having a predetermined frequency and emits the pulse light, the light amount control unit may further control at least one of a frequency and a peak power of the pulse light emitted from the optical

25 modulator. In such a case, in addition to the individual step-by-step on/off control of the output of each fiber making up the optical fiber group, a fine adjustment of

the light amount in between the steps becomes possible by controlling at least either the frequency or the peak power of the pulse light emitted from the optical modulator. As a consequence, continuous control of the light amount becomes possible, and if the set exposure amount is within a predetermined range the light amount of the output light can be made to coincide with the set light amount, whatever value the set light amount may be.

[0035]

In the light source unit related to each invention according to Claims 1 to 13, as in the invention according to Claim 14, according to the present invention, the light source unit may further comprise a delay portion (167), which individually delays light output from the plurality of optical fibers respectively so as to stagger the light output temporally. In such a case, since the light is not emitted from each optical fiber at the same time, consequently, the spatial coherency can be reduced.

[0036]

The invention according to Claim 15 is a light source unit that generates light with a single wavelength, the light source unit comprising: a light generating portion (160) that has a light source (160A) which generates light with a single wavelength and an optical modulator (160C) which converts light from the light source into a pulse light with a predetermined frequency and emits the

pulse light; a light amplifying portion (161) which includes at least one fiber amplifier to amplify the pulse light generated by the light generating portion; and a light amount control unit (16C) which controls

5   light amount of light output from the fiber amplifier by controlling a frequency of the pulse light emitted from the optical modulator.

[0037]

With the light source unit, light with a single

10 wavelength is generated from the light source in the light generating portion, and the light is converted and emitted as a pulse light with a predetermined frequency by the optical modulator. And this pulse light is amplified in the light amplifying portion, and is emitted

15 as a pulse light having a greater peak power. On the other hand, if the peak power of the pulse light is almost fixed, then the light amount of the pulse light per unit time fluctuates depending on the frequency of the pulse light. So, by controlling the frequency of the

20 pulse light emitted from the optical modulator with the light amount control unit, the light amount of the emitted light from the fiber amplifier can be made to coincide with the set light amount (target light amount). With the light amount adjustment by controlling the

25 frequency of the pulse light (the number of pulse per unit time) according to the present invention, a faster and finer light amount adjustment becomes possible

compared with the invention according to Claim 1, and if the set light amount is within a predetermined range the light amount can be made to almost coincide with the set light amount, whatever value the set light amount may be.

5   In addition, the linearity between the light output and the control amount is equal to or better than the invention according to Claim 1.

[0038]

In this case, as in the invention according to Claim

10   16, when the light source unit further comprises a memory unit (51) which has an output intensity map of the light amplifying portion corresponding to a frequency of the pulse light entering the light amplifying portion stored, the light amount control unit may control the frequency

15   of the pulse light emitted from the optical modulator based on the output intensity map and a predetermined set light amount. The intensity of the light incident on the light amplifying unit changes according to the frequency of the pulse light from the optical modulator, and the

20   gain of the fiber amplifier structuring the light amplifying portion has an incident light intensity dependence. However, according to the present invention, light amount control with high precision is possible, without being affected by the change in the peak power of

25   the pulse output from the light amplifying portion due to the incident light intensity dependence.

[0039]

In each invention according to Claims 15 and 16, as in the invention according to Claim 17, the light amount control unit may further control the peak power of the pulse light emitted from the optical modulator. In such a

5   case, light amount control with favorable precision is possible even in the case when there is a change in the peak power of the pulse light.

[0040]

In each invention according to Claims 15 and 16, as

10   in the invention according to Claim 18, in the case the optical modulator is an electrooptical modulator, the light amount control unit may control the frequency of the pulse light by controlling a frequency of voltage pulse impressed on the optical modulator. The frequency

15   of the pulse light emitted from the electrooptical modulator coincides with the frequency of the voltage pulse impressed on the optical modulator.

[0041]

The invention according to Claim 19 is a light source

20   unit that generates light with a single wavelength, the light source unit comprising: a light generating portion (160) that has a light source (160A) which generates light with a single wavelength and an optical modulator (160C) which converts light from the light source into a

25   pulse light with a predetermined frequency and emits the pulse light; a light amplifying portion (161) which includes at least one fiber amplifier to amplify the

pulse light generated by the light generating portion; and a light amount control unit (16C) which controls light amount of light output from the light amplifying portion by controlling the peak power of the pulse light

5   emitted from the optical modulator.

[0042]

With the third light source unit, light with a single wavelength is generated from the light source in the light generating portion, and the light is converted and

10   emitted as a pulse light with a predetermined frequency by the optical modulator. And this pulse light is amplified in the light amplifying portion, and is emitted as a pulse light having a greater peak power. The light amount of the pulse light emitted from the light

15   amplifying portion per unit time, naturally fluctuates in accordance with the peak power of the pulse light emitted from the optical modulator. So, by controlling the peak power of the pulse light emitted from the optical modulator with the light amount control unit, the light

20   amount of the emitted light from the fiber amplifier can be made to coincide with the set light amount (target light amount). With the light amount adjustment by controlling the peak power of the pulse light according to the present invention, a faster and finer light amount

25   adjustment becomes possible compared with the invention according to Claim 1, and if the set light amount is within a predetermined range the light amount can be made

to almost coincide with the set light amount, whatever value the set light amount may be.

[0043]

In this case, as in the invention according to Claim

5   20, when the light source unit further comprises a memory unit (51) which has an output intensity map of the light amplifying portion corresponding to intensity of the pulse light entering the light amplifying portion stored, the light amount control unit may control the peak power

10   of the pulse light emitted from the optical modulator based on the output intensity map and a predetermined set light amount. In such a case, light amount control with high precision becomes possible, without being affected by the change in peak power of the pulse light emitted

15   from the light amplifying portion which is caused by the input light intensity dependence of the gain of the fiber amplifier structuring the light amplifying portion.

[0044]

In each invention according to Claims 19 and 20, as

20   in the invention according to Claim 21, the optical modulator may be an electrooptical modulator, and the light amount control unit may control the peak power of the pulse light by controlling a peak level of voltage pulse impressed on the optical modulator. The pulse peak

25   intensity of the light emitted from the electrooptical modulator depends on the pulse peak intensity of the voltage pulse impressed on the electrooptical modulator.

[0045]

In the light source unit related to each invention according to Claims 15 to 21, as in the invention according to Claim 22, the light amplifying portion may

5 be arranged in plural and in parallel, and an output end of each light amplifying portion may each be made up of an optical fiber.

[0046]

In this case, as in the invention according to Claim

10 23, a plurality of optical fibers that respectively make up the light amplifying portion in plural may be bundled so as to structure a bundle-fiber (173). In general, since the diameter of the optical fiber is narrow, even when a hundred fibers and over are bundled, the diameter

15 of the bundle is within a few mm, thus, a compact optical element can be arranged in the case when an optical element of some kind is arranged on the output side of the bundle fiber.

[0047]

20 In the light source unit related to each invention according to Claims 15 to 23, as in the invention according to Claim 24, the light source unit may further comprise a wavelength conversion portion (163), which converts a wavelength of light emitted from the light

25 amplifying portion. In such a case, the light amount of the light emitted from the wavelength conversion portion is a value corresponding to the output of the light

amplifying portion, in other words, the input intensity
of the pulse light from the optical modulator. The value,
however, is not always definitely proportional to the
input intensity (light amount) of the pulse light, and

5   shows a nonlinear dependence proportional to the power
number of the harmonic order of the harmonic wave emitted
from the wavelength conversion portion at a maximum, in
respect to the peak intensity of the pulse light emitted
from the light amplifying portion. Meanwhile, in the case

10   when the optical modulator is an electrooptical modulator,
the pulse peak intensity dependence of the pulse peak
intensity of the light emitted from the electrooptical
modulator to the voltage pulse impressed on the
electrooptical modulator is expressed as cos(V),

15   therefore, the nonlinear dependence of the wavelength
conversion portion is eased. Accordingly, in the case the
light source unit comprises a wavelength conversion
portion, it is preferable for the optical modulator to be
an electrooptical modulator.

20   **[0048]**

In each invention according to Claims 22 and 23, as
in the invention according to Claim 25, the light source
unit may further comprise a delay portion (167), which
individually delays light output from the plurality of

25   light amplifying portions respectively so as to stagger
the light output temporally. In such a case, since the
light is not emitted from each optical fiber at the same

time, consequently, the spatial coherency can be reduced.

[0049]

In the light source unit related to each invention according to Claims 11, 12 and 24, as in the invention according to Claim 26, the light generating portion may generate a single wavelength laser beam within a range of infrared to visible region, and the wavelength conversion portion may emit ultraviolet light which is a harmonic wave of the single wavelength laser beam.

[0050]

In this case, as in the invention according to Claim 27, the light generating portion can generate a single wavelength laser beam that has a wavelength of around 1.5μm, and the wavelength conversion portion may generate one of an eighth-harmonic wave and a tenth-harmonic wave of the single wavelength laser beam having the wavelength of around 1.5μm.

[0051]

The invention according to Claim 28 is an exposure apparatus which transfers a pattern formed on a mask (R) onto a substrate (W), the exposure apparatus comprising: the light source unit (16) according to one of Claims 26 and 27; and an illumination optical system (12) which illuminates a light emitted from the light source unit onto the mask as an illumination light for exposure.

[0052]

With the exposure apparatus, the mask is illuminated

by the illumination optical system with the ultraviolet light emitted from a wavelength conversion portion of the light source unit as the illumination light for exposure, and the pattern formed on the mask is transferred onto

5 the substrate. In this case, the light source unit can control the light amount of the ultraviolet light irradiated on the mask depending on the requirements, therefore, as a consequence, the required exposure amount control can be achieved.

10 **[0053]**

In this case, as in the invention according to Claim 29, an optical integrator (22) that uniforms a distribution of the illumination light on a pattern surface of the mask may be arranged within the

15 illumination optical system. In particular, in the case a plurality of optical fibers are arranged in parallel, it is especially preferable to arrange the optical integrator because the optical integrator can suppress the change of the illumination light distribution on the

20 mask surface due to the change of light output from each optical fiber (including on/off operation).

[0054]

In the exposure apparatus related to each invention according to one of Claims 28 and 29, as in the invention

25 according to Claim 30, the illumination optical system may be a Koehler illumination system.

[0055]

The invention according to Claim 31 is an exposure apparatus which repeatedly transfers a pattern formed on a mask onto a substrate, the exposure apparatus comprising: a light generating portion (160) that has a

5   light source (160A) which generates light with a single wavelength and an optical modulator (160C) which converts light from the light source into a pulse light; a light amplifying portion (161) which includes at least one fiber amplifier to amplify a pulse light generated in the

10   light generating portion; a control unit (50) which controls at least one of a frequency and a peak power of the pulse light via the optical modulator in accordance with a position of an area subject to exposure on the substrate, when the substrate is exposed via the mask by

15   irradiating the amplified pulse light on the mask.

[0056]

With the exposure apparatus, the light generating portion generates a pulse light with the optical modulator by converting light with a single wavelength

20   generated by the light source, and the pulse light is amplified by the light amplifying portion including the fiber amplifier. And when the control unit irradiates the amplified pulse light on the mask and the substrate is exposed via the mask, either of the frequency or the peak

25   power of the pulse light is controlled via the optical modulator according to the position of the area subject to exposure on the substrate. With this operation, the

light amount irradiated on the mask, and furthermore, the exposure amount on the substrate is controlled with high precision. Accordingly, with the present invention, an appropriate exposure amount control becomes possible at

5 all times regardless of the position of the area subject to exposure on the substrate, and it becomes possible to transfer the mask pattern onto the substrate with favorable accuracy.

[0057]

10 The "area subject to exposure," here, is a concept that includes both the respective shot areas when there is a plurality of shot areas on the substrate to expose, and the different areas in each shot area. Accordingly, with the present invention, correction of process

15 variation in each shot area on the substrate in the so-called stepper (including the scanning stepper) or improvement in line width uniformity within a shot area in the scanning exposure apparatus becomes possible.

[0058]

20 The invention according to Claim 32 is an exposure apparatus which transfers a pattern formed on a mask (R) onto a substrate (W), the exposure apparatus comprising: a light generating portion (160) that has a light source (160A) which generates light with a single wavelength and

25 an optical modulator (160C) which converts light from the light source into a pulse light; a light amplifying portion (161) made up of a plurality of optical paths

(172_n) arranged in parallel on an output side of the light generating portion, the optical paths including at least one fiber amplifier to amplify the pulse light; and a control unit (50) which controls the light amount of the

5　pulse light emitted from the light amplifying portion by individually turning on/off light output from the plurality of optical paths respectively, when the substrate is exposed via the mask by irradiating the pulse light emitted from the light amplifying portion on

10　the mask.

[0059]

With the exposure apparatus, the light generating portion generates a pulse light with the optical modulator by converting light with a single wavelength

15　generated by the light source, and the pulse light is amplified by the light amplifying portion including the fiber amplifier. And when the control unit irradiates the amplified pulse light on the mask and the substrate is exposed via the mask, the light amount of the pulse light

20　emitted from the light amplifying portion by individually turning on/off the light output from each optical path. With this operation, the light amount irradiated on the mask, and furthermore, the exposure amount on the substrate is controlled step-by-step in a wide range.

25　Accordingly, with the present invention, exposure amount control depending on the different resist sensitivity of each wafer in an exposure apparatus that repeatedly

performs exposure on a plurality of substrates becomes possible. Thus, it becomes possible to transfer a mask pattern on the substrate with a required accuracy.

[0060]

5   In this case, as well, the control unit may control at least either the frequency or the peak power of the pulse light via the optical modulator in correspondence with the position of the area subject to exposure on the substrate, as is described earlier.

10   **[0061]**

In each invention according to Claims 31 and 32, as in the invention according to Claim 33, the light source may generate a laser beam in one of an infrared and a visible region, and the exposure apparatus may further

15   comprise a wavelength conversion portion which converts a wavelength of the pulse light amplified in the light amplifying portion into a wavelength of ultraviolet light.

[0062]

The invention according to Claim 34 is an exposure

20   method which repeatedly transfers a pattern formed on a mask onto a substrate, the exposure method including: a first step of amplifying a pulse light using a fiber amplifier at least once; a second step of exposing an area subject to exposure on the substrate via the mask by

25   irradiating the amplified pulse light onto the mask; and a third step of converting a laser beam emitted from a light source to the pulse light and controlling at least

one of a frequency and a peak power of the pulse light in accordance with a position of the area subject to exposure on the substrate, prior to the first step.

[0063]

5   With the first exposure method, the pulse light is amplified at least once using the fiber amplifier, the amplified pulse light is irradiated on the mask, and the area subject to exposure on the substrate is exposed via the mask.   In this case, prior to amplifying the pulse

10   light with the fiber amplifier, the laser beam from the light source is converted into the pulse light, and in addition, at least either of the frequency and the peak power of the pulse light is controlled in correspondence with the position of the area subject to exposure on the

15   substrate. Accordingly, when the area subject to exposure on the substrate is exposed via the mask by irradiating the pulse light on the mask, exposure is performed in a state in which the exposure amount is adjusted according to the position of the area subject to exposure on the

20   substrate.   Accordingly, with the present invention, an appropriate exposure amount control is possible at all times regardless of the position of the area subject to exposure on the substrate, and it becomes possible to transfer the pattern of the mask onto the substrate with

25   high accuracy.

[0064]

The "area subject to exposure," here, is a concept

that includes both the respective shot areas when there is a plurality of shot areas on the substrate to expose, and the different areas in each shot area. Accordingly, with the present invention, correction of process variation in each shot area on the substrate in the so-called stepper (including the scanning stepper) or improvement in line width uniformity within a shot area in the scanning exposure apparatus becomes possible.

[0065]

In this case, as in the invention according to Claim 35, when the fiber amplifier is arranged in plural and in parallel, in the first step, the pulse light may be amplified by using only the selected fiber amplifiers. In such a case, the exposure amount control can be performed step-by-step in a wide dynamic range. Therefore, by employing this control together with the exposure amount control referred to earlier of controlling at least either of the frequency and the peak power of the pulse light in correspondence with the position of the area subject to exposure on the substrate, an exposure amount control of a wider range can be performed with high precision. And by selecting the fiber amplifiers depending on the resist sensitivity of the substrate and the like, exposure amount control is possible in accordance with the difference of the resist sensitivity of each wafer.

[0066]

In each invention according to Claims 34 and 35, as in the invention according to Claim 36, the light source may generate a laser beam in one of an infrared and a visible region, and the exposure method may further

5   include: a fourth step of performing wavelength conversion on the amplified pulse light for conversion into an ultraviolet light before the pulse light is irradiated on the mask.

[0067]

10   The invention according to Claim 37 is a device manufacturing method including a photolithographic process, wherein exposure is performed using the exposure apparatus according to any one of Claims 28 to 33 in the photolithographic process. Also, the invention according

15   to Claim 38 is a device manufacturing method including a photolithographic process, wherein the exposure method according to any one of Claims 34 to 36 is used in the photolithographic process.

[0068]

20   With these device manufacturing methods, it becomes possible to transfer a pattern of a mask onto a substrate with good precision using each exposure apparatus according to Claims 28 to 33 and each exposure method according to Claims 34 to 36, and consequently the

25   productivity of the microdevice with high integration can be improved.

[0069]

[EMBODIMENT OF THE INVENTION]

An embodiment of the present invention will be described below with reference to Figs. 1 to 6.

[0070]

Fig. 1 shows the schematic view of the exposure apparatus 10 related to the embodiment, which structure includes the light source unit related to the present invention. The exposure apparatus 10 is a scanning type exposure apparatus based on the step-and-scan method.

[0071]

The exposure apparatus 10 comprises: an illumination system consisting of a light source unit 16 and an illumination optical system 12; a reticle stage RST that holds a reticle R serving as a mask which is illuminated by the illumination light for exposure (hereinafter referred to as "exposure light") IL from the illumination system; a projection optical system PL which projects the exposure light IL outgoing from the reticle R onto a wafer W serving as a substrate; an XY stage 14 on which a Z tilt stage 58 serving as a substrate stage holding the wafer W is mounted; control systems for these parts; and the like.

[0072]

The light source unit 16 is, for example, a harmonic generation unit that emits an ultraviolet pulse light having a wavelength of 193nm (almost the same wavelength as of the ArF excimer laser beam) or an ultraviolet pulse

light having a wavelength of 157nm (almost the same wavelength as of the F_2 laser beam). The light soruce unit 16 comprises a light source portion 16A including a laser light source as a light source, a laser controller

5 16B, and a light amount controller 16C. The light source unit 16 is housed within an environmental chamber (hereinafter referred to as "chamber") 11 where the temperature, pressure, humidity, and the like are adjusted with high precision. In the environmental

10 chamber 11, the illumination optical system 12, the reticle stage RST, the projection optical system PL, the Z tilt stage 58, the XY stage 14, and a main body of the exposure apparatus consisting of a main column (not shown in Figs.) on which these parts are arranged, are also

15 housed.

   [0073]

   Fig. 2 is a block diagram showing the internal structure of the light source unit 16 along with the main controller 50, which performs overall control over the

20 entire exposure apparatus.

   [0074]

   As is shown in Fig. 2, the light source portion 16A has a structure including a pulse light generation portion 160 serving as a light generation portion, a

25 light amplifying portion 161, a quarter-wave plate 162, a wavelength conversion portion 163, a beam monitor mechanism 164, an absorption cell 165, and the like.

[0075]

The pulse light generation portion 160 has a laser light source 160A, photocoupler BS1 and BS2, optical isolator 160B, an electro-optic modulator (hereinafter

5   referred to as "EOM") 160C serving as an optical modulator, and the like. And, each element arranged in between the laser light source 160A and the wavelength conversion portion 163 is optically connected to one another by optical fiber.

10   **[0076]**

As the laser light source 160A, in this case, a single wavelength oscillation laser is used, for example, an InGaAsP DFB semiconductor laser, which has an oscillation wavelength of 1.544μm, continuous-wave output

15   (hereinafter referred to as "CW output") of 20mW, is used. Hereinafter in this description, the laser light source 160A will be referred to as "DFB semiconductor laser 160A", as appropriate.

[0077]

20   DFB semiconductor laser, in this description, is a diffraction grating made within the semiconductor laser, instead of the Fabry-Perot resonator having low longitudinal mode selectivity, and is structured to oscillate a single longitudinal mode in any circumstances.

25   It is called the distributed feedback (DFB) laser, and since this type of laser basically performs a single longitudinal mode oscillation, the oscillation spectral

line width can be suppressed so that it does not exceed 0.01pm.

[0078]

In addition, the DFB semiconductor laser is usually arranged on a heatsink, and these are housed in a casing. With the embodiment, a temperature adjustment unit (for example, a Peltier element) is arranged on the heatsink of the DFB semiconductor laser 160A, and as will be described later on, the embodiment has a structure so that the laser controller 16B is capable of controlling (adjusting) the oscillation wavelength by controlling the temperature of the temperature adjustment unit.

[0079]

That is, the temperature dependence of the oscillation wavelength of the DFB semiconductor laser 160A is around 0.1nm/°C. Accordingly, if the temperature of the DFB semiconductor laser changes 1°C, the wavelength of the reference wave (1544nm) changes 0.1nm. So, in the case of an eighth-harmonic wave (193nm) the wavelength changes 0.0125nm, and in the case of a tenth-harmonic wave (157nm) the wavelength changes 0.01nm.

[0080]

With the exposure apparatus, it is sufficient enough if the wavelength of the illumination light for exposure (pulse light) varies around ±20pm in respect to the center wavelength. Accordingly, in the case of the eighth-harmonic wave the temperature of the DFB

semiconductor laser 11 needs to vary around ±1.6°C, and in the case of the tenth-harmonic wave the temperature needs to vary around ±2°C.

[0081]

5   The laser light source 160A is not limited to semiconductor lasers such as the DFB semiconductor laser. For example, the ytteribium (Yb) doped fiber laser which has an oscillation wavelength of around 990nm can be used.

[0082]

10   The photocoupler BS1 and BS2 have a transmittance of around 97%. Therefore, the laser beam from the DFB semiconductor laser 160A is separated at the photocoupler BS1, and around 97% of the separated beam is incident on the photocoupler BS2, whereas, the remaining 3% is

15   incident on the beam monitor mechanism 164. Furthermore, the laser beam incident on the photocoupler BS2 is separated, and around 97% of the separated beam proceeds to the optical isolator 160B, whereas, the remaining 3% is incident on the absorption cell 165.

20   **[0083]**

The beam monitor mechanism 164, the absorption cell 165, and the like will be described in detail later on in the description.

[0084]

25   The optical isolator 160B is a device, which allows only light proceeding from the photocoupler BS2 to the EOM160C to pass, and prevents light proceeding in the

opposite direction from passing. The optical isolator 160B prevents the oscillation mode of the DFB semiconductor laser 160A from changing or noise from being generated, which are caused by the reflecting light
5   (returning light).

[0085]

The EOM160C is a device, which converts the laser beam (CW beam (continuous-wave beam) that has passed through the optical isolator 160B into a pulse light. As
10   the EOM160C, an electrooptical modulator (for example, a double-electrode modulator) that has an electrode structure having performed chirp correction is used, so that the wavelength broadening of the semiconductor laser output by chirp due to temporal change in the refractive
15   index is decreased. The EOM160C emits a pulse light modulated in synchronous with the voltage pulse impressed from the light amount controller 16C. For example, if the EOM160C modulates the laser beam oscillated from the DFB semiconductor laser 160A into a pulse light with a pulse
20   width of 1ns and a repetition frequency of 100kHz (pulse period around 10µs), as a result of this optical modulation, the peak output of the pulse light emitted from the EOM160 is 20mW, and the average output 2µW. In this case, the insertion of the EOM160C does not create
25   any loss, however, in the case there is a loss by insertion, for example, when the loss is -3dB, the peak output of the pulse light becomes 10mW, and the average

output 1μW.

[0086]

In the case of setting the repetition frequency to around 100kHz and over, it is preferable to prevent the

5 amplification reduction due to the noise effect of the ASE (Amplified Spontaneous Emission) with the fiber amplifier. The details on this will be described later on in the description.

[0087]

10 When only the EOM160C is used and the pulse light is turned off, in the case the extinction ratio is not sufficient enough, it is preferable to use the current control of the DFB semiconductor laser 160A. That is, since with semiconductor lasers and the like, the emitted

15 light can be pulse oscillated by performing current control, it is preferable to generate the pulse light by utilizing both the current control of the DFB semiconductor laser 160A and the EOM160C. For example, if a pulse light having a width of around 10 - 20 ns is

20 oscillated by the current control of the DFB semiconductor laser 160A and is partially extracted and modulated by the EOM160C into a pulse light having a width of around 1ns, it becomes possible to generate a pulse light that has a narrow pulse width compared with

25 the case when using only the EOM160C, and can also further simplify the control of the oscillation interval and the beginning/end of the oscillation of the pulse

light.

[0088]

Alternately, it is possible to use an acousto-optic modulator (AOM) instead of the EOM160C.

5   **[0089]**

The light amplifying portion 161 amplifies the pulse light from the EOM160C, and in this case, is structured including a plurality of fiber amplifiers. An example of the arrangement of the light-amplifying portion 161 is

10   shown in Fig. 3 with the EOM160C.

[0090]

As shown in Fig. 3, the light amplifying portion 161 comprises: a delay portion 167, which has a total of 128 channels from 0 to 127; fiber amplifiers 168_1 - 168_{128}

15   which are respectively connected to the output side of the channels 0 to 127 (a total of 128 channels) of the delay portion 167; narrow-band filters 169_1 - 169_{128}, optical isolators 170_1 - 170_{128}, fiber amplifiers 171_1 - 171_{128}, which are connected to the output side of the

20   fiber amplifiers 168_1 - 168_{128} in this order, and the like. In this case, as is obvious from Fig. 3, the fiber amplifier 168_n, the narrow-band filter 169_n, the optical isolator 170_n, and the fiber amplifier 171_n (n=1, 2, ..., 128) respectively make up the optical path 172_n (n=1, 2,

25   ......, 128).

[0091]

To further describe each structuring portion of the

light amplifying portion 161, the branch and delay portion 167 has a total of 128 channels, and provides a predetermined delay time (in this case 3ns) to the output of each channel. In this embodiment, the structure of the

5 delay portion 167 includes: an erbium (Er)-doped fiber amplifier (EDFA), which performs a 35dB (x 3162) optical amplification on the pulse light emitted from the EOM160C; a splitter (1 planar waveguide x 4 splitters) serving as an optical branch unit which divides in

10 parallel the output of the EDFA into four (channels 0 to 3) outputs; four optical fibers with different lengths, which are respectively connected to the output end of the channels 0 to 3 of the splitter; four splitters (1 planar waveguide x 32 splitters) which divides the output of the

15 four optical fibers respectively into 32 (channels 0 to 31); and 31 optical fibers each (a total of 124 optical fibers) having different lengths, which are respectively connected to the channels 1 to 31 (excluding channel 0) of each splitter. Hereinafter, the channels 0 to 31 of

20 each splitter (1 planar waveguide x 32 splitters) will be referred to as a "block" in general.

[0092]

More particularly, the pulse light emitted from the EDFA has a peak output of around 63W, and the average

25 output is around 6.3W. This pulse light is divided in parallel into four outputs, to channel 0 to 3 by the splitter (1 planar waveguide x 4 splitters), and a delay

corresponding to the length of the four optical fibers is provided to the light emitted from each channel. For example, in the embodiment, when the propagation velocity of light in the optical fiber is 2 x 10^8m/s, and the

5   length of the optical fibers connected to the channels 0, 1, 2, and 3 of the splitter (1 planar waveguide x 4 splitters) are 0.1m, 19.3m, 38.5m, and 57.7m respectively (hereinafter referred to as the "first delay fiber"), then the delay of light between adjacent channels at the

10   emitting side of the first delay fiber is 96ns.

[0093]

In addition, to the channels 1 to 31 of the four splitters (1 splitter: 1 planar waveguide x 32 splitters), optical fibers (hereinafter referred to as the "second

15   delay fiber") respectively having the length of 0.6 x N (N = channel number) are connected. As a consequence, a delay of 3ns is provided between adjacent channels within each block. And in respect to the output of channel 0 in each block, a delay of 3x31=93ns is provided to the

20   output of channel 31.

[0094]

Meanwhile, in between each block, from the first block to the fourth block, the first delay fiber respectively provides a delay of 96ns at the input stage

25   of each block, as is described above. Accordingly, the channel 0 output of the second block is provided a delay of 96ns in respect to the channel 0 output of the first

block, and a delay of 3ns in respect to the channel 31 output of the first block. This is likewise, between the second and third block, and the third and fourth block. And as a consequence, as the entire output, on the

5   emitting side of the 128 channels, a pulse light that has a 3ns delay in between adjacent channels can be obtained.

[0095]

From the branch and delay described above, on the emitting side of the 128 channels, the pulse light that

10   has a 3ns delay in between adjacent channels is obtained, and the light pulse that can be observed at each emitting end is 100kHz (pulse period 10μs), which is the same as the pulse modulated by the EOM 160C. Accordingly, from the viewpoint of the entire laser beam generating portion,

15   the repetition of the next pulse train being generated at an interval of 9.62μs after 128 pulses are generated at an interval of 3ns, is performed at 100kHz. That is, the total output becomes $128 \times 100 \times 10^3 = 1.28 \times 10^7$ pulse/second.

[0096]

20   With the embodiment, the example was of the case when the channel was divided into 128 and the delay fibers used were short, thus, in between pulse trains an interval of 9.62μs occurred where no light was emitted. However, by increasing the number of divided channels, or

25   by using a longer delay fiber with an appropriate length, or by combining both methods, it is possible to make the pulse interval completely equal.

[0097]

In the embodiment, the erbium (Er)-doped fiber amplifier (EDFA) which mode field diameter of the optical fiber (hereinafter referred to as "mode diameter") is 5 - 6μm, likewise with the optical fiber normally used for communication, is used as the fiber amplifier 168_n (n=1, 2, ..., 128). The fiber amplifier 168_n amplifies the emitted light from each channel of the delay portion 167 according to a predetermined amplifier gain. The pumped light source and the like of the fiber amplifier 168_n will be described later in the description.

[0098]

The narrow-band filter 169_n (n=1, 2, ..., 128) cuts the ASE generated at the fiber amplifier 168_n while allowing the output wavelength (wavelength width around 1pm or under) of the DFB semiconductor laser 160A to pass, so that the wavelength width of the light transmitted is substantially narrowed. This can prevent the amplifier gain being reduced by the ASE being incident on the fiber amplifier 171_n arranged on the output side, or the laser beam from scattering due to traveling the noise of the ASE. It is preferable for the narrow-band filter 169_n to have a transmission wavelength width of around 1pm, however, since the wavelength width of the ASE is around several tens (nm) the ASE can be cut with the current narrow-band filter having the transmission wavelength width of around 100pm to an extent so that there are

substantially no serious problems.

[0099]

In addition, in the embodiment, since there are cases when the output wavelength of the DFB semiconductor laser 160A is positively changed, as will be described later, it is preferable to use a narrow-band filter that has a transmission wavelength width (the same level or above the variable width) in accordance with the variable width of the output wavelength (the variable width of the exposure apparatus in the embodiment is, for example, around ±20pm). With the laser unit applied in the exposure apparatus, the wavelength width is set around 1pm and under.

[0100]

The optical isolator 170_n (n=1, 2, ..., 128) reduces the effect of the returning light, likewise with the optical isolator 160B described earlier.

[0101]

As the fiber amplifier 171_n (n=1, 2, ..., 128), in the embodiment, in order to avoid the spectral width of the amplified light from increasing due to the nonlinear effect in the optical fiber, the mode diameter of the optical fiber used is wider than the optical fiber normally used for communication (5 - 6µm). For example, an EDFA with a wide diameter of around 20 - 30µm is used. The fiber amplifier 171_n further amplifies the light emitted from each channel of the delay portion 167 that

have already been amplified with the fiber amplifier 168_n. As an example, when the average output of each channel of the delay portion 167 is around 50μW and the average output of all the channels is around 6.3mW, and an

5   amplification of a total of 46dB (x 40600) is performed by the fiber amplifier 168_n and the fiber amplifier 171_n, at the output end of the optical path 172_n corresponding to each channel (the output end of the optical fiber making up the fiber amplifier 171_n), the peak output of

10   20kW, the pulse width 1ns, the pulse repetition frequency 100kHz, the average output 2W, and the average output of all the channels 256W are obtained. The pumped light source and the like of the fiber amplifier 171_n will also be described later in the description.

15   **[0102]**

In the embodiment, the output end of the optical path 172_n corresponding to each channel of the delay portion 167, that is, the output end of the optical fiber making up the fiber amplifier 171_n, is bundled to form a bundle-

20   fiber 173, which has a sectional shape as is shown in Fig. 4. The cladding diameter of each optical fiber is around 125μm, therefore, the diameter of the bundle of 128 optical fibers at the output end can be around 2mm or under. In the embodiment, the bundle-fiber 173 is formed

25   using the output end of the fiber amplifier 171_n itself, however, a non-doped optical fiber can be connected to each output end of the fiber amplifier 171_n and the

bundle-fiber can be formed by bundling these optical fibers.

[0103]

The fiber amplifier 168_n that has an average mode diameter and the fiber amplifier 171_n that has a wide mode diameter are connected using an optical fiber which mode diameter increases in the shape of a truncated cone.

[0104]

Next, the pumped light source and the like of each fiber amplifier are described with reference to Fig. 5. Fig. 5 schematically shows the fiber amplifiers and their neighboring area structuring the light amplifying portion 161, with a partial view of the wavelength conversion portion 163.

[0105]

In Fig. 5, a semiconductor laser 178 for pumping is fiber coupled to the fiber amplifier 168_n, and the output of the semiconductor laser 178 is input into the doped fiber for the fiber amplifier through the wavelength division multiplexer (WDM) 179. The doped fiber is pumped with this operation.

[0106]

Meanwhile, with the fiber amplifier 171_n having a wide mode diameter, a semiconductor laser 174 that serves as a pumping light source to pump the doped fiber for the fiber amplifier having a wide mode diameter is fiber coupled to the fiber with the wide mode diameter, which

diameter matches that of the doped fiber for the fiber amplifier. And the output of the semiconductor laser 174 is input to the doped fiber for the optical amplifier, and thus the doped fiber is pumped.

5   **[0107]**

The laser beam amplified with the wide mode diameter (fiber amplifier) 171_n is incident on the wavelength conversion portion 163, and the wavelength of the laser beam is converted to generate the ultraviolet laser beam.

10   The arrangement of the wavelength conversion portion and the like will be described, later in the description.

[0108]

It is preferable for the laser beam (signals) transmitted through the wide mode diameter (fiber

15   amplifier) 171_n to be mainly in the fundamental mode, and this can be achieved by selectively pumping the fundamental mode in a single mode or multimode fiber with a low mode order.

[0109]

20   With the embodiment, four high-powered semiconductor lasers are fiber coupled to the wide mode diameter fiber in both the proceeding direction of the laser beam (signals) and the direction opposite. In this case, in order to effectively couple the semiconductor laser beam

25   for pumping to the doped fiber for optical amplification, it is preferable to use an optical fiber which cladding has a double structure as the doped fiber for optical

amplification. And, the semiconductor laser beam for pumping is guided into the inner cladding of the dual cladding by the WDM 176.

[0110]

5   The semiconductor lasers 178 and 174 are controlled by the light amount controller 16C.

[0111]

In addition, in the embodiment, since the fiber amplifiers 168_n and 171_n are provided as the optical fiber

10   making up the optical path 172_n, the gain difference in each fiber amplifier becomes the dispersion of the light emitted at each channel. Therefore, in the embodiment, the output is partially branched at the fiber amplifier of each channel (168_n and 171_n) and is photo-electrically

15   converted by the photoconversion elements 180 and 181 arranged respectively at the branched end. And the output signals of these photoconversion elements 180 and 181 are sent to the light amount controller 16C.

[0112]

20   The light amount controller 16C feedback controls the drive current of each pumping semiconductor laser (178 and 174) so that the light emitted from each fiber amplifier is constant (that is, balanced) at each amplifying stage.

25   **[0113]**

Furthermore, with the embodiment, as is shown in Fig. 5, the laser beam split by the beam splitter halfway

through the wavelength conversion portion 163 is photo-electrically converted by the photoconversion element 182, and the output signal of the photoconversion element 182 is sent to the light amount controller 16C. The light

5   amount controller 16C then monitors the light intensity of the wavelength conversion portion 163 based on the output signals of the photoconversion element 182, and feedback controls the drive current of at least either the pumping semiconductor laser 178 or the pumping

10   semiconductor laser 174 so that the light output from the wavelength conversion portion 163 becomes a predetermined light output.

[0114]

By having this arrangement, since the amplification

15   of the fiber amplifier in each channel is constant at each amplifying stage, a unified light intensity can be obtained as a whole without an overload on either fiber amplifier. In addition, by monitoring the light intensity of the wavelength conversion portion 163, the expected

20   predetermined light intensity can be fed back to each amplifier, and the desired ultraviolet light output can be stably obtained.

[0115]

Details on the light amount controller 16C will be

25   described later in the description.

[0116]

From the light amplifying portion 161 (the output

side of each optical fiber forming the bundle-fiber 173)
having the arrangement described above, the pulse light
is emitted, on which circular polarization has been
performed.   The circular polarized pulse light is
5 converted to a linear polarized pulse light where the
polarized direction is all the same by the quarter-wave
plate 162 (refer to Fig. 2), and is then incident on the
wavelength conversion portion 163.

[0117]

10 The wavelength conversion portion 163 includes a
plurality of nonlinear optical crystals, and converts the
wavelength of the amplified pulse light (light having the
wavelength of 1.544μm) into an eighth-harmonic wave or a
tenth-harmonic wave so that ultraviolet light that has
15 the same output wavelength as the ArF excimer laser
(wavelength: 193nm) or the F_2 laser (wavelength: 157nm) is
generated.

[0118]

Fig. 6(A) and Fig. 6(B) show examples of the
20 arrangement of the wavelength conversion portion 163.
Following is a description of concrete examples on the
wavelength conversion portion 163, with reference to
these Figures.

[0119]

25 Fig. 6(A) shows an example of the arrangement when
ultraviolet light having the same wavelength as the ArF
excimer laser (193nm) is generated by converting the

/

fundamental wave of the wavelength 1.544μm output from the emitting end of the bundle-fiber 173 using the nonlinear optical crystals into an eighth-harmonic wave. In addition, Fig. 6(B) shows an example of the

5 arrangement when ultraviolet light having the same wavelength as the F_2 laser (157nm) is generated by converting the fundamental wave of the wavelength 1.57μm output from the emitting end of the bundle-fiber 173 using the nonlinear optical crystals into a tenth-

10 harmonic wave.

[0120]

At the wavelength conversion portion in Fig. 6(A), the wavelength conversion is performed in the order of: fundamental wave (wavelength: 1.544μm) → second-harmonic

15 wave (wavelength: 772nm) → third-harmonic wave (wavelength: 515nm) → fourth-harmonic wave (wavelength: 386nm) → seventh-harmonic wave (wavelength: 221nm) → eighth-harmonic wave (wavelength: 193nm).

[0121]

20 More particularly, the fundamental wave output from the emitting end of the bundle-fiber 173 that has the wavelength of 1.544μm (frequency ω) is incident on the first stage nonlinear optical crystal 533. When the fundamental wave passes through the nonlinear optical

25 crystal 533, by the second-harmonic generation a second-harmonic wave which frequency is doubled from the frequency ω of the fundamental wave, that is, a second-

harmonic wave with a frequency of 2ω (the wavelength is half, which is 772nm) is generated.

[0122]

As the first stage nonlinear optical crystal 533, an
5   LiB_3O_5(LBO) crystal is used, and NCPM (Non-Critical Phase Matching), which is a method of adjusting the temperature of the LBO crystal for phase matching to convert the wavelength of the fundamental wave to a second-harmonic wave, is employed. NCPM is capable of converting the
10   fundamental wave into a second-harmonic wave with high efficiency, since walk-off between the fundamental wave and the second-harmonic wave does not occur within the nonlinear optical crystal, and also because of the advantage that the beam shape of the second-harmonic wave
15   generated does not change by the walk-off.

[0123]

The fundamental wave that has passed through the nonlinear optical crystal 533 without the wavelength converted and the second-harmonic wave generated by the
20   wavelength conversion are respectively provided a delay of a half wave and a single wave at a wavelength plate 534 at the next stage.. Only the fundamental wave rotates the polarized direction by 90 degrees, then the fundamental wave and the second-harmonic wave are
25   incident on the second stage nonlinear optical crystal 536. As the second nonlinear optical crystal 536, an LBO crystal is used, and the LBO crystal is used in NCPM at a

temperature different from the first nonlinear optical crystal (LBO crystal) 533. In the nonlinear optical crystal 536, a third-harmonic wave (wavelength: 515nm) is generated by sum frequency generation of the second-

5   harmonic wave generated in the first nonlinear optical crystal 533 and of the fundamental wave that has passed through the nonlinear optical crystal 533 without the wavelength converted.

[0124]

10 Then, the third-harmonic wave obtained in the nonlinear optical crystal 536 and the fundamental wave and the second-harmonic wave that have passed through the nonlinear optical crystal 536 without being converted are separated at the dichroic mirror 537, and the third-

15 harmonic wave reflected on the dichroic mirror 537 passes through the condenser lens 540 and the dichroic mirror 543 and is incident on the fourth stage nonlinear optical crystal 545. Meanwhile, the fundamental wave and the second-harmonic wave that have passed through the

20 dichroic mirror 537 passes through a condenser lens 538 and are incident on the third stage nonlinear optical crystal 539.

[0125]

The LBO crystal is used as the third stage nonlinear

25 optical crystal 539, and the fundamental wave passes through the LBO crystal without being converted, whereas, the second-harmonic wave is converted to a fourth-

harmonic wave (wavelength: 386nm) in the LBO crystal by second-harmonic generation. The fourth-harmonic wave obtained in the third nonlinear optical crystal 539 and the fundamental wave that has passed through the third

5 nonlinear optical crystal 539 are separated at the dichroic mirror 541, and the fundamental wave that has passed through the dichroic mirror 541 passes through the condenser lens 544 and is reflected on the dichroic mirror 546, and is incident on the fifth stage nonlinear

10 optical crystal 548. On the other hand, the fourth-harmonic wave reflected on the dichroic mirror 541 passes through the condenser lens 542 and reaches the dichroic mirror 543, and is coaxially synthesized with the third-harmonic wave reflected on the dichroic mirror 537 and

15 then is incident on the fourth stage nonlinear optical crystal 545.

[0126]

As the fourth stage nonlinear optical crystal 545, a β-BaB_2O_4(BBO) crystal is used, and a seventh-harmonic wave

20 (wavelength: 221nm) is generated by sum frequency generation of the third -harmonic wave and the fourth-harmonic wave. The seventh-harmonic wave generated in the fourth nonlinear optical crystal 545 passes through the condenser lens 547, and is coaxially synthesized with

25 fundamental wave that has passed through the dichroic mirror 541 at the dichroic mirror 546, and is then incident on the fifth stage nonlinear optical crystal 548.

[0127]

As the fifth stage nonlinear optical crystal 548, the LBO crystal is used, and an eighth-harmonic wave (wavelength: 193nm) is generated by sum frequency generation of the fundamental wave and the seventh-harmonic wave. In the arrangement above, instead of the BBO crystal 545 used to generate the seventh-harmonic wave and the LBO crystal 548 used to generate the eight-harmonic wave, it is also possible to use a $CsLiB_6O_{10}$ (CLBO) crystal and a $Li_2B_4O_7$ (LB4) crystal.

[0128]

With the arrangement example in Fig. 6(A), since the third-harmonic wave and the fourth-harmonic wave proceed through different optical paths and are incident on the fourth stage nonlinear optical crystal 545, the lens 540 to condense the third-harmonic wave and the lens 542 to condense the fourth-harmonic wave can be arranged on separate optical paths. The sectional shape of the fourth-harmonic wave generated in the third nonlinear optical crystal 539 is elliptic due to the walk-off phenomenon. Therefore, in order to obtain favorable conversion efficiency in the fourth stage nonlinear optical crystal 545, it is preferable to perform beam shaping on the fourth-harmonic wave. In this case, since the condenser lens 540 and 542 are arranged on different optical paths, for example, a pair of cylindrical lens can be used as the lens 542 to easily perform beam

shaping on the fourth-harmonic wave. This makes it possible for the fourth-harmonic wave to overlap the third-harmonic wave favorably at the fourth stage nonlinear optical crystal 545, and the conversion

5 efficiency can be increased.

[0129]

Furthermore, the lens 544 to condense the fundamental wave incident on the fifth stage nonlinear optical crystal 548 and the lens 547 to condense the seventh-

10 harmonic wave can be arranged on different optical paths. The sectional shape of seventh-harmonic wave generated in the fourth stage nonlinear optical crystal 545 is elliptic due to the walk-off phenomenon. Therefore, in order to obtain favorable conversion efficiency in the

15 fifth stage nonlinear optical crystal 548, it is preferable to perform beam shaping on the seventh-harmonic wave. In the embodiment, since the condenser lens 544 and 547 can be arranged on different optical paths, for example, a pair of cylindrical lens can be

20 used as the lens 547 to easily perform beam shaping on the seventh-harmonic wave. Thus, the seventh-harmonic wave can favorably overlap the fundamental wave at the fifth stage nonlinear optical crystal (LBO crystal) 548, and the conversion efficiency can be increased.

25 [0130]

The structure in between the second stage nonlinear optical crystal 536 and the fourth stage nonlinear

optical crystal 545 is not limited to the arrangement shown in Fig. 6(A). It can have any arrangement, so long as the third-harmonic wave, generated in the nonlinear optical crystal 536 and reflected on the dichroic mirror

5   537, and the fourth-harmonic wave, obtained by converting the wavelength of the second-harmonic wave generated in the nonlinear optical crystal 536 which passes through the dichroic mirror 537 in the nonlinear optical crystal 539, are both incident at the same time on the nonlinear

10   optical crystal 545, and the length of the optical paths in between both nonlinear optical crystals 536 and 545 is equal. The same can be said of the structure in between the third stage nonlinear optical crystal 539 and the fifth stage nonlinear optical crystal 548.

15   [0131]

According to an experiment performed by the inventor, in the case of Fig. 6(A), the average output of the eighth-harmonic wave (wavelength: 193nm) in each channel was around 45.9mW. Accordingly, the average output of the

20   bundle of the entire 128 channels becomes 5.9W, therefore, ultraviolet light having a wavelength of 193nm can be provided, which is sufficient enough as an output of a light source for an exposure apparatus.

     [0132]

25   In this case, on generating an eighth-harmonic wave (wavelength: 193nm), currently, the LBO crystal, which has good quality and can be purchased easily on the

market, is used. Since the LBO crystal has an extremely small absorption coefficient to the ultraviolet light having a wavelength of 193nm, and the optical damage of the crystal does not create a serious problem, the LBO

5   crystal is advantageous in durability.

[0133]

In addition, at the generating portion of the eighth-harmonic wave (wavelength: 193nm), angular phase matching is performed on the LBO crystal used, however, since the

10 phase matching angle is large, the effective nonlinear optical constant (d_{eff}) becomes small. Therefore, it is preferable to use the LBO crystal at a high temperature by providing a temperature control mechanism to the LBO crystal. This can reduce the phase matching angle, that

15 is, the constant referred to above (d_{eff}) can be increased, and the generation efficiency of the eighth-harmonic wave can be improved.

[0134]

At the wavelength conversion portion in Fig. 6(B),

20 the wavelength conversion is performed in the order of: fundamental wave (wavelength: 1.57µm) → second-harmonic wave (wavelength: 785nm) → fourth-harmonic wave (wavelength: 392.5nm) → eighth-harmonic wave (wavelength: 196.25nm) → tenth-harmonic wave (wavelength: 157nm). In

25 this arrangement example, upon each wavelength conversion from the second-harmonic wave generation to the eighth-harmonic wave generation, second-harmonic generation is

performed on each wavelength when it enters each wavelength conversion.

[0135]

Also, in this arrangement example, as the nonlinear optical crystal used for wavelength conversion, the LBO crystal is used for the nonlinear optical crystal 602 that generates a second-harmonic wave from a fundamental wave by second-harmonic generation, and for the nonlinear optical crystal 604 that generates a fourth-harmonic wave from the second-harmonic wave by second-harmonic generation. Furthermore, as the nonlinear optical crystal 609, which generates an eighth-harmonic wave from the fourth-harmonic wave by second-harmonic generation, an $Sr_2Be_2B_2O_7$ (SBBO) crystal is used. And, as the nonlinear optical crystal 611, which generates a tenth-harmonic wave (wavelength: 157nm) by sum frequency generation of the second-harmonic wave and the eighth-harmonic wave, the SBBO crystal is used.

[0136]

The second-harmonic wave generated in the nonlinear optical crystal 602 passes through the condenser lens 603 and is incident on the nonlinear optical crystal 604, and the nonlinear optical crystal 604 generates the fourth-harmonic wave described above, as well as a second-harmonic wave that is not converted. The second-harmonic wave, which has passed through the dichroic mirror 605, then passes through the condenser lens 606 and is

reflected on the dichroic mirror 607, and then is incident on the nonlinear optical crystal 611. Whereas, the fourth-harmonic wave, which is reflected on the dichroic mirror 605, passes through the condenser lens

5 608 and is incident on the nonlinear optical crystal 609, and the eighth-harmonic wave generated in the nonlinear optical crystal 609 proceeds to the condenser lens 610 and the dichroic mirror 607, and then is incident on the nonlinear optical crystal 611. Furthermore, the nonlinear

10 optical crystal 611 generates the tenth-harmonic wave (wavelength: 157nm) by sum frequency generation of the second-harmonic wave and the eighth-harmonic wave, which are coaxially synthesized at the dichroic mirror 607.

[0137]

15 In this arrangement example, the arrangement was made so that the second-harmonic wave and the fourth-harmonic wave generated in the second stage nonlinear optical crystal 604 were separated at the dichroic mirror 605, and the second-harmonic wave having passed through the

20 dichroic mirror 605 and the eighth-harmonic wave obtained by converting the wavelength of the fourth-harmonic wave at the nonlinear optical crystal 609 went through different optical paths before being incident on the fourth stage nonlinear optical crystal 611. Alternately,

25 the dichroic mirrors 605 and 607 do not have to be used, and the four nonlinear optical crystals 602, 604, 609, and 611 may have a coaxial arrangement.

[0138]

However, in the arrangement example, the sectional shape of the fourth-harmonic wave generated in the second stage nonlinear optical crystal 604 is elliptic due to the walk-off phenomenon. Therefore, in order to obtain favorable conversion efficiency in the fourth stage nonlinear optical crystal 611 where this beam is incident, it is preferable to perform beam shaping on the fourth-harmonic wave, which is the incident beam, and create a favorable overlap with the second-harmonic wave. In this arrangement example, since the condenser lenses 606 and 608 are arranged on different optical paths, for example, it is possible to use the cylindrical lens as the lens 608, which makes the beam shaping of the fourth-harmonic wave easier. Thus, the fourth-harmonic wave can favorably overlap the second-harmonic wave at the fourth stage nonlinear optical crystal 611, and the conversion efficiency can be increased.

[0139]

It is a matter of course, that the wavelength conversion portion shown in Figs. 6(A) and 6(B) are mere examples, and the arrangement of the wavelength conversion portion in the present invention are not limited to them.

[0140]

Referring back to Fig. 2, the beam monitor mechanism 164 is made up of a Fabry-Perot etalon (hereinafter also

referred to as "etalon element") and an energy monitor consisting of a photoconversion element such as a photodiode (neither is shown in Figs.). The beam incident on the etalon element structuring the beam monitor

5   mechanism 164 passes through the etalon element with a transmittance that corresponds to the frequency difference of the resonance frequency of the etalon element and the frequency of the incident beam. And the output signals of the photodiode and the like, which

10   detect the intensity of the transmitted beam, are sent to the laser controller 16B. The laser controller 16B performs a predetermined signal processing on the output signals, and obtains information related to the optical properties of the incident beam on the beam monitor

15   mechanisms 164, to be precise, on the etalon element (to be concrete, information such as the center wavelength of the incident beam and the width of the wavelength (spectral half-width)) and the like. And the information related to the optical properties is sent to the main

20   controller 50 realtime.

[0141]

The frequency characteristic of the transmitted light intensity that the etalon element generates is affected by the temperature or pressure of atmosphere, and in

25   particular, the resonance frequency (resonance wavelength) is temperature dependent. Therefore, it is important to study the temperature dependence of the

resonance wavelength in order to precisely control the center wavelength and spectral half-width of the laser beam oscillated from the laser light source 160A based on the detection results of the etalon element. In the

5 embodiment, the temperature dependence of the resonance wavelength is measured in advance, and the measurement results are stored as a temperature dependence map in the memory 51 (refer to Fig. 1) serving as a storage unit, which is arranged with the main controller 50. And, the

10 main controller 50 gives instructions to the laser controller 16B to positively control the temperature of the etalon element within the beam monitor mechanism 164, so that the resonance wavelength (detection reference wavelength) maximizing the transmittance of the etalon

15 element precisely coincides with the set wavelength in cases such as absolute wavelength calibration of the beam monitor mechanism 164, which will be described later on.

   [0142]

In addition, the output of the energy monitor

20 structuring the beam monitor mechanism 164 is sent to the main controller 50, and the main controller 50 detects the energy power of the laser beam based on the output of the energy monitor and controls the light amount of the laser beam oscillated from the DFB semiconductor laser

25 160A via the laser controller 16B or turns off the DFB semiconductor laser 160A when necessary. In the embodiment, however, as will be described later on, the

light amount control (exposure amount control) is usually performed mainly by the light amount controller 16C, by controlling the peak power or frequency of the pulse light emitted from the EOM160C or by on/off control of

5   the light emitted from each fiber amplifier structuring the light amplifying portion 161. Accordingly, the main controller 50 controls the laser controller 16B in the manner described above when the energy power of the laser beam changes greatly for some reason.

10   **[0143]**

The absorption cell 165 is an absolute wavelength source for absolute wavelength calibration of the oscillation wavelength of the DFB semiconductor laser 160A, in other words, is the absolute wavelength source

15   for absolute wavelength calibration of the beam monitor mechanism 164. In the embodiment, since the DFB semiconductor laser 160A having the oscillation wavelength of 1.544μm is used as the light source, an isotope of acetylene having dense absorption lines in the

20   wavelength band around the wavelength of the DFB semiconductor laser 160A is used as the absorption cell 165.

[0144]

As will be described later on, in the case of

25   selecting intermediate waves of the wavelength conversion portion 163 (such as the second-harmonic wave, the third harmonic wave, and the fourth harmonic wave) or light

which wavelength has been converted with, or in alternate of the fundamental wave as the light for monitoring the wavelength of the laser beam, the absorption cell that has dense absorption lines around the wavelength of the

5 intermediate wave can be used. For example, in the case of selecting the third-harmonic wave as the light for monitoring the wavelength of the laser beam, iodine molecules that have dense absorption lines around the wavelength of 503nm to 530nm can be used as the

10 absorption cell. The appropriate absorption line of the iodine molecules can be chosen, and the wavelength of the absorption line can be determined as the absolute wavelength.

[0145]

15 In addition, the absolute wavelength source is not limited to the absorption cell, and the absolute wavelength light source may also be used.

[0146]

The laser controller 16B detects the center

20 wavelength and the wavelength width (spectral half-width) of the laser beam based on the output of the beam monitor mechanism 164, and performs the temperature control (and current control) of the DFB semiconductor laser 160A by feedback control so that the center wavelength becomes a

25 desired value (set wavelength). In the embodiment, it is possible to control the temperature of the DFB semiconductor laser 160A in the unit of 0.001°C.

[0147]

In addition, the laser controller 16B switches the output of the DFB semiconductor 160A between the pulse output and the continuous output and controls the output interval and pulse width during pulse output, as well as control the oscillation of the DFB semiconductor laser 160A so as to compensate the output variation of the pulse light, in accordance with instructions from the main controller 50.

[0148]

In this manner, the laser controller 16B stabilizes the oscillation wavelength to a constant wavelength, as well as finely adjust the output wavelength. On the contrary, the laser controller 16B may also adjust the output wavelength of the DFB semiconductor laser 160A by positively changing the oscillation wavelength in accordance with instructions from the main controller 50.

[0149]

For example, with the former control, generation or change in aberration (image forming characteristics) of the projection optical system PL due to change in wavelength can be prevented, thus change in image characteristics (optical properties such as image quality) during pattern transfer can be avoided.

[0150]

In addition, with the latter control, variation in image forming characteristics (such as aberration) of the

projection optical system PL occurring due to the difference in altitude and pressure between the place where the exposure apparatus was made and adjusted and where the exposure apparatus is arranged (delivered) or

5   the difference in the environment (atmosphere of the clean room), can be cancelled out, and the start-up time of the exposure apparatus at the delivery site can be reduced. Furthermore, with the latter control, change in aberration, projection magnification, and focal position

10 of the projection optical system PL due to the irradiation of the illumination light for exposure and atmospheric change can also be canceled out during the operation of the exposure apparatus, and it becomes possible to transfer the pattern image onto the substrate

15 in the best image forming state.

[0151]

The light amount controller 16C has the following functions: stabilizing the amplification of the fiber amplifiers at each channel at each amplifying stage, by

20 performing feedback control on the drive current of each pumping semiconductor laser (178 and 174) based on the output of the photoconversion elements 180 and 181 that detect the light emitted from the fiber amplifiers 168_n and 171_n within the light amplifying portion 161; and

25 stabilizing the desired ultraviolet output by performing feedback control on the drive current of at least either the pumping semiconductor laser 178 or the pumping

semiconductor laser 174 and feeding back the predetermined light intensity expected to each amplifying stage, based on the output signal of the photoconversion element 182, which detects the light split by the beam
5   splitter along the wavelength conversion portion 163.

[0152]

Furthermore, in the embodiment, the light amount controller 16C has the following functions.

[0153]

10   That is, the light amount controller 16C has the functions of:

① Controlling the average light output of the bundle in total by performing individual on/off control on the output of the fiber of each channel making up the bundle-
15   fiber 173, in other words, the output of each optical path 172_n, in accordance with instructions from the main controller 50 (hereinafter referred to as the "first function" for the sake of convenience);

② Controlling the average light output (output energy)
20   per unit time of each channel in the light amplifying portion 161, in other words, the intensity of the light emitted per unit time from each optical path 172_n, by controlling the frequency of the pulse light emitted from the EOM160C in accordance with instructions from the main
25   controller 50 (hereinafter referred to as the "second function" for the sake of convenience); and

③ Controlling the average light output (output energy)

per unit time of each channel in the light amplifying portion 161, in other words, the intensity of the light emitted per unit time from each optical path 172_n, by controlling the peak power of the pulse light emitted

5   from the EOM160C in accordance with instructions from the main controller 50 (hereinafter referred to as the "third function" for the sake of convenience).

[0154]

Details of the first, second, and third functions

10   will now be described.

[0155]

First of all, the light amount controller 16C performs the on/off operation on each optical path 172_n referred to in the first function, by performing the

15   on/off operation on the output of each channel of the fiber amplifier 171_n. In this case, the light amount controller 16C can perform the operation by performing on/off operation on the fiber amplifier pumping semiconductor laser 174, in other words, by selectively

20   setting the intensity of the pumped light from the semiconductor laser 174 to either a predetermined level or to a zero level. Or, the light amount controller 16C can perform the operation by adjusting the drive current value of the semiconductor laser 174 so that the

25   intensity of the pumped light from the semiconductor laser 174 is selectively set to a first level where the fiber amplifier 171_n is in a state capable of amplifying,

or to a second level where the fiber amplifier 171_n is not in a state capable of amplifying. In the state not capable of amplifying, the light absorption becomes larger, and the output from the fiber amplifier is almost

5   zero, therefore, the output of each optical path 172_n is turned off.

[0156]

In the case of performing on/off operation on the semiconductor laser 174, when the semiconductor laser 174

10   is in an off state, no power is consumed, therefore, energy saving becomes possible. On the other hand, in the case of switching the intensity of the pumped light from the semiconductor laser 174 between the first level and the second level, the first level and the second level

15   may be a fixed value, but does not necessarily have to be a fixed value. That is, with the fiber amplifier, the state where it is or is not capable of amplifying is determined by whether the intensity of the pumped light is above or below a certain value.

20   **[0157]**

According to the first function of the light amount controller 16C, the average light output (light amount) of the whole bundle is controllable by $1/128^{th}$ of the maximum light output (by around 1% and under). That is,

25   the dynamic range can be set at a wide range of 1 - 1/128. Since each optical path 172_n is made up of the same structuring material, designwise, the light output of the

optical path 172_n is supposed to be equal, therefore light amount control by $1/128^{th}$ is to have good linearity.

[0158]

In addition, with the embodiment, the wavelength conversion portion 163 is arranged to perform wavelength conversion on the output of the light amplifying portion 161, that is, on the output of the bundle-fiber 173. The output of the wavelength conversion portion 163 is proportional to the output of each optical path 172_n, that is, to the number of fibers of the fiber amplifier 171_n in an on state. Therefore, in principle, a linear light amount control by $1/128^{th}$ of the maximum light output (by around 1% and under) is possible.

[0159]

However, in actual, possibilities are high that the output of each optical path 172_n is dispersed or the wavelength conversion efficiency in respect to the output of each optical path 172_n is dispersed due to manufactural errors and the like. Therefore, the output dispersion of each optical fiber (optical path 172_n), the output dispersion due to the wavelength conversion efficiency dispersion in respect to the output of each optical fiber, and the like are measured in advance. And based on the measurement results, a first output intensity map, which is a map on intensity of light output from the wavelength conversion portion 163 corresponding to the on/off state of the light output of each optical fiber (a conversion

table of output intensity corresponding to the fiber
group in the "on" state), is made, and stored in the
memory 51 arranged along with the main controller 50. The
first output intensity map stored in the memory 51, may

5   be in the form of a table, or it may be in the form of a
function or a coefficient.   It is likewise, with the
second and third intensity map, which will be described
later in the description.

[0160]

10   And, the light amount controller performs light
amount control based on the set light amount provided
from the main controller 50 and the intensity map
described above, when performing the light amount control
related to the first function.

15   [0161]

In addition, the light amount controller 16C controls
the frequency of the pulse light emitted from the EOM160C
in the second function described above by changing the
frequency of the rectangular wave (voltage pulse)

20   impressed on the EOM160C.   Since the frequency of the
pulse light emitted from the EOM160C coincides with the
frequency of the voltage pulse impressed on the EOM160C,
the frequency of the pulse light emitted is to be
controlled by controlling the impressed voltage.

25   [0162]

In the embodiment, as is previously described, the
frequency of the rectangular wave impressed on the

EOM160C is 100kHz. For example, if the frequency is increased to 110kHz, then the number of the light pulse per unit time increases by 10%, and the delay portion 167 sequentially divides each pulse to the total of 128 channels, from channel 0 to 127, in the same manner as described above. As a consequence, the pulse light per unit time in each channel increases by 10%, and if the light energy per light pulse is the same, that is, the peak power of the pulse light is constant, then, the output light intensity (light amount) of each optical path 172_n per unit time also increases by 10%.

[0163]

In addition, in the embodiment, the wavelength conversion portion 163, which converts the wavelength of the emitted light from each channel of the light amplifying portion 161, is arranged, and the light amount of the light emitted per unit time of the wavelength conversion portion 163 is proportional to the frequency of the output pulse of each channel, if the peak power is constant. Accordingly, the light amount control of the second function is control with excellent linearity.

[0164]

The pulse light emitted from the EOM160C, however, is input to the fiber amplifiers 168_n and 171_n via the delay portion 167, therefore, in actual, the linearity may not always be as stated above. That is, in general, the amplification gain of the fiber amplifier has input light

intensity dependence, so if the frequency of the output light of the EOM160C is changed, there may be cases where the input light intensity of the fiber amplifiers 168_n and 171_n changes, and as a result, the peak power of the pulse

5 light emitted from the fiber amplifiers 168_n and 171_n may also change. It is possible, to suppress the change in peak power by designing the fiber amplifiers 168_n and 171_n appropriately, however, this may reduce the light output efficiency and other performances of the fiber amplifiers.

10 **[0165]**

Thus, in the embodiment, the input frequency intensity dependence of the output of fiber amplifiers is measured in advance. And based on this measurement, the second output intensity map, which is a map on intensity

15 of light output from (each channel of) the light amplifying portion 161 corresponding to the frequency of the pulse light input to the light amplifying portion 161 (a conversion table of output intensity of the light amplifying portion 161, corresponding to the frequency of

20 light emitted from the EOM) is made, and stored into the memory 51.

[0166]

And, when the light amount controller 16C performs the light amount control in the second function, the

25 light amount control is performed based on the set light amount provided from the main controller 50 and the second output intensity map described above.

[0167]

In addition, the light amount controller 16C controls the peak power of the pulse light emitted from the EOM160 in the third function described above, by controlling the

5   peak intensity of the voltage pulse impressed on the EOM160C. This is because the peak power of the emitted light from the EOM160C is dependent on the peak intensity of the voltage pulse impressed on the EOM160C.

[0168]

10   Also, in the embodiment, the wavelength conversion portion 163, which converts the wavelength of the emitted light from each channel of the light amplifying portion 161, is arranged, and the output light intensity of the wavelength conversion portion 163 shows a dependence in a

15   nonlinear shape proportional to the power number of the harmonic order at the maximum, in respect to the peak intensity of the pulse light emitted from each optical fiber (optical path 172_n). For example, on generating light of 193nm by eighth-harmonic generation as is in Fig.

20   6(A), the output intensity of the light having the wavelength of 193nm shows the intensity change, which is proportional to the peak power of the fiber amplifier output to the eighth power, at the maximum.

[0169]

25   In the case of the embodiment, since the dependence of the peak power of the pulse light emitted from the EOM160C in respect to the peak intensity of the voltage

pulse impressed on the EOM160C is cos(V), as a consequence, the nonlinear dependence of the wavelength conversion portion 163 described above is eased. Accordingly, with the light source unit having a

5 wavelength conversion portion as in the embodiment, it is meaningful to perform intensity (light amount) control of the light emitted by controlling the peak intensity of the voltage pulse impressed on the EOM160C.

[0170]

10 However, as is described earlier, the amplifier gain of the fiber amplifier has input light intensity dependence, therefore, if the peak intensity of the pulse light emitted from the EOM160C is changed, there may be cases where the input light intensity of the fiber

15 amplifiers 168_n and 171_n changes, and as a result, the peak power of the pulse light emitted from the fiber amplifiers 168_n and 171_n may also change. It is possible, to suppress the change in peak power by designing the fiber amplifiers 168_n and 171_n appropriately, however,

20 this may reduce the light output efficiency and other performances of the fiber amplifiers.

[0171]

So, in the embodiment, the input pulse peak intensity dependence of the output of fiber amplifiers is measured

25 in advance. And based on this measurement, the third output intensity map, which is a map on intensity of light output from (each channel of) the light amplifying

portion 161 corresponding to the peak intensity of the pulse light input to the light amplifying portion 161 (a conversion table of output pulse light intensity of the light amplifying portion 161, corresponding to the peak intensity of light emitted from the EOM) is made, and stored into the memory 51. The third output intensity map may be an ultraviolet intensity map, which serves as the wavelength conversion portion output.

[0172]

And, when the light amount controller 16C performs the light amount control in the third function, the light amount control is performed based on the set light amount provided from the main controller 50 and the third output intensity map described above.

[0173]

It is possible to arrange another EOM for transmittance control other than the EOM160C at the output side of the DFB semiconductor laser 160A. And the transmittance of the EOM can be changed by changing the voltage impressed to the EOM, so as to change the energy emitted from the light amplifying portion and wavelength conversion portion per unit time.

[0174]

As can be seen from the description so far, in the second and third function of the light amount controller 16C, finer light amount control of the emitted light from the light source unit 16 is possible when compared with

the first function. On the other hand, in the first function, the dynamic range can be set at a wider level, when compared with the second and third function.

[0175]

5   Therefore, in the embodiment, on the exposure that will be described later on, rough adjustment of the exposure amount is to be performed according to the first function of the light amount controller 16C, and fine adjustment is to be performed using the second and third

10   function. This will be referred to later in the description.

[0176]

Other than the controls above, the light amount controller 16C also controls the start/stop of the pulse

15   output in accordance with instructions from the main controller 50.

[0177]

Referring back to Fig. 1, the illumination optical system 12 comprises: a beam shaping optical system 18; a

20   fly-eye lens system 22 serving as an optical integrator (a homogenizer); an illumination system aperture stop plate 24; a beam splitter 26; a first relay lens 28A; a second relay lens 28B; a fixed reticle blind 30A; a movable reticle blind 30B; a mirror M for deflecting the

25   optical path; a condenser lens 32; and the like.

[0178]

The beam shaping optical system 18 shapes the

sectional shape of the light in the ultraviolet region (hereinafter referred to as "laser beam") LB generated by converting the wavelength of light emitted from the light source unit 16 at the wavelength conversion portion 163

5   so that it is efficiently incident on the fly-eye lens system 22, which is arranged downstream of the optical path of the laser beam LB. The beam shaping optical system 18, for example, is made up of a cylindrical lens or a beam expander (neither is shown in Figs.).

10   **[0179]**

The fly-eye lens system 22 is arranged on the optical path of the laser beam LB emitted from the beam shaping optical system 18, and forms a planar light source, that is, a secondary light source, which consists of many

15   light source images (point light sources), to illuminate the reticle R with a uniform illuminance distribution. The laser beam emitted from the secondary light source, is also referred to as "exposure light IL", in this description.

20   **[0180]**

In the vicinity of the emitting surface of the fly-eye lens 22, the illumination system aperture stop plate 24, which is made of a plate-shaped member, is arranged. On the illumination system aperture stop plate 24, a

25   plurality of aperture stops are arranged at substantially equal angular intervals. The aperture stops may have an ordinary circular aperture, or it may have a small

circular-shaped aperture for reducing the σ-value, which is a coherence factor. It may also have a ring-shaped aperture for ring-shaped illumination, or a plurality of apertures (for example, four apertures) of which each

5 central position differ from the optical axis position for modified illumination (in Fig. 1, only two of these aperture stops are shown). The illumination system aperture stop plate 24 is rotated by a driving unit 40 such as a motor, controlled by the main controller 50,

10 and either aperture stop is selectively chosen to be set on the optical path of the exposure light IL in correspondence with the reticle pattern.

[0181]

On the optical path of the exposure light IL outgoing

15 from the illumination system aperture stop plate 24, the beam splitter 26, which has a large transmittance and a small reflectance, is arranged. And further downstream on the optical path, the relay optical system, structured of the first relay lens 28A and the second relay lens 28B is

20 arranged, with the fixed reticle blind 30A and the movable reticle blind 30B arranged in between.

[0182]

The fixed retile blind 30A is arranged on a surface slightly defocused from the conjugate plane relative to

25 the pattern surface of the reticle R, and a rectangular opening is formed to set the illumination area 42R on the reticle R. In addition, close to the fixed retile blind

30A, the movable reticle blind 30B is arranged. The movable reticle blind 30B has an opening portion, which position and width is variable in the scanning direction, and by further restricting the illumination area 42R via

5　the movable reticle blind 30B during the start and completion of the scanning exposure, exposure on unnecessary portions can be avoided.

[0183]

On the optical path of the exposure light IL further

10　downstream of the second relay lens 28B structuring the relay optical system, the deflection mirror M is arranged to reflect and bend the exposure light IL that has passed through the second relay lens 28 toward the reticle R, and on the optical path beyond the mirror M, the

15　condenser lens 32 is arranged.

[0184]

Furthermore, on either side of the optical path vertically bent at the beam splitter 26 within the illumination optical system 12, an integrator sensor 46

20　and a reflection light monitor 47 are respectively arranged. As the integrator sensor 46 and the reflection light monitor 47, a silicon PIN type photodiode is used, which is sensitive to light in the far ultraviolet region and the vacuum ultra violet region and also has high

25　response frequency to detect the pulse emission of the light source unit 16. Or, it is possible to use a semiconductor photodetection element having a GaN crystal

as the integrator sensor 46 and the reflection light
monitor 47.

[0185]

With the structure described above, the incident
5   surface of the fly-eye lens system 22, the arrangement
surface of the movable reticle blind 30B, and the pattern
surface of the reticle R, are arranged optically
conjugated with each other. And, the light source surface
formed on the outgoing side of the fly-eye lens system 22
10 and the Fourier transform surface of the projection
optical system PL (exit pupil surface) are arranged
optically conjugated with each other, forming a Koehler
illumination system.

[0186]

15 The operation of the illumination optical system 12
having the structure described above will now be briefly
described. The laser beam LB, pulse-emitted from the
light source unit 16, is incident on the beam shaping
optical system 18, and the sectional shape of the laser
20 beam LB is shaped so that it is efficiently incident on
the fly-eye lens system 22, which is arranged further
downstream. The laser beam LB, is then incident on the
fly-eye lens system 22, and the secondary light source is
formed on the focal plane of the emitting side of the
25 fly-eye lens system 22 (the pupil surface of the
illumination optical system 12). The exposure light IL
outgoing from the secondary light source, then passes

through one of the aperture stops on the illumination system aperture stop plate 24, and reaches the beam splitter 26, which has a large transmittance and a small reflectance. The exposure light IL, which passes through

5   the beam splitter 26 proceeds to the first relay lens 28A, and then passes through the rectangular opening of the fixed reticle blind 30A and the movable reticle blind 30B. After passing through the movable reticle blind 30B, the exposure light IL passes through the second relay lens

10 28B, and the optical path is then bent vertically downward by the mirror M. The exposure light IL, then passes through the condenser lens 32 and illuminates the rectangular illumination are 42R on the reticle R held on the reticle stage RST with a uniform illuminance

15 distribution.

[0187]

Meanwhile, the exposure light IL, which is reflected off the beam splitter 26, passes through the condenser lens 44 and is photo-detected by the integrator sensor 46.

20 And the photoelectric conversion signal of the integrator sensor 46 is sent to the main controller 50 as the output DS (digit/pulse) via a peak hold circuit and an A/D converter (not shown in Figs.). The relative coefficient of the output DS of the integrator sensor 46 and the

25 illuminance (exposure amount) of the exposure light IL on the surface of the wafer W is obtained in advance, and is stored in the memory 51 serving as a storage unit

arranged with the main controller 50.

[0188]

In addition, the exposure light, which illuminates the illumination area 42R on the reticle R and is
5 reflected off the pattern surface of the reticle (the lower surface in Fig. 1), proceeds backward in the opposite direction as before through the condenser lens 32 and the relay lens system, and is reflected off the beam splitter 26 and photo-detected by the reflection
10 light monitor 47 via the condenser lens 48. In addition, in the case the Z tilt stage 58 is arranged below the projection optical system PL, the exposure light IL, which has passed through the pattern surface of the reticle, is reflected off the projection optical system
15 PL and the surface of the wafer W (or the surface of the fiducial mark plate FM, which will be described later), and proceeds backward in the order of the projection optical system PL, the reticle R, the condenser lens 32, and the relay lens system, and is reflected off the beam
20 splitter 26 to be photo-detected by the reflection light monitor 47 via the condenser lens 48. Also, although the surface of each optical element arranged in between the beam splitter 26 and the wafer W has a lens coating to prevent reflection, an extremely small amount of the
25 exposure light IL is reflected on the surface, and the reflection light is also photo-detected by the reflection light monitor 47. The photoconversion signals of the

reflection monitor 47 are supplied to the main controller 50 via the peak hold circuit and the A/D converter (not shown in Figs.). The reflection monitor 47 is mainly used to measure the reflectance of the wafer W in the

5 embodiment. The reflection monitor 47 may also be used to measure the transmittance of the reticle R in advance.

[0189]

As the fly-eye lens system, for example, a double fly-eye lens system, which details are disclosed in,

10 Japanese Patent Laid Open No. 01-235289 (the corresponding U.S. Patent No. 5,307,207), and in Japanese Patent Laid Open No. 07-142354 (the corresponding U.S. Patent No. 5,534,970), may be employed to structure a Koehler illumination system.

15 **[0190]**

In addition, a diffractive optical element may be used with the fly-eye lens system 22. In the case of using such a diffractive optical element, the light source unit 16 and the illumination optical system 12 may

20 be connected with the diffractive optical element arranged in between.

[0191]

That is, in correspondence with each fiber of the bundle-fiber, the diffractive optical element on which

25 the diffractive element is formed can be arranged in the beam shaping optical system 18, and the laser beam emitted from each fiber can be diffracted so that the

beams are superimposed on the incident surface of the
fly-eye lens system 22. In the embodiment, the output end
of the bundle-fiber may be arranged on the pupil surface
of the illumination optical system. In this case, however,

5   the intensity distribution (in other words, the shape and
size of the secondary light source) on the pupil surface
varies due to the first function (partial on/off to
reduce total output), and may not be the most suitable
shape and size for the reticle pattern. Thus, it is

10 preferable to use the diffractive optical element and the
like described earlier, to superimpose the laser beam
from each fiber on the pupil surface of the illumination
optical system or on the incident surface of the optical
integrator.

15   **[0192]**

In any case, in the embodiment, even if the
distribution of the portion that emits light from the
bundle-fiber 173 varies, uniform illuminance distribution
on both the pattern surface (object surface) of the

20 reticle R and the surface (image plane) of the wafer W
can be sufficiently secured due to the first function of
the light amount controller 16C, referred to earlier.

        [0193]

The reticle R is mounted on the reticle stage RST,

25 and is held on the stage by vacuum chucking (not shown in
Figs.). The reticle stage RST is finely drivable within a
horizontal surface (XY plane), as well as scanned in the

scanning direction (in this case, the Y direction, being the landscape direction in Fig. 1) within a predetermined stroke range by the reticle stage driving portion 49. The position and rotational amount of the reticle stage RST

5   during scanning, is measured via the movable mirror 52R fixed to the reticle stage RST by the laser interferometer 54R arranged externally, and the measurement values of the laser interferometer 54R is supplied to the main controller 50.

10   **[0194]**

The material used for the reticle R depends on the wavelength of the exposure light IL. That is, in the case of using exposure light with the wavelength of 193nm, synthetic quartz can be used. In the case of using

15   exposure light with the wavelength of 157nm, however, the reticle R needs to be made of fluorite, fluorine-doped synthetic quartz, or crystal.

[0195]

The projection optical system PL is, for example, a

20   double telecentric reduction system, and is made up of a plurality of lens elements 70a, 70b, ..., which have a common optical axis in the Z-axis direction. In addition, as the projection optical system PL, a projection optical system having a projection magnification β of, for

25   example, 1/4, 1/5, or 1/6, is used. Therefore, when the illumination area 42R on the reticle R is illuminated with the exposure light IL as is described earlier, the

pattern formed on the reticle R is projected and transferred as a reduced image by the projection magnification β with the projection optical system PL on the slit-shaped exposure area 42W on the wafer W, which

5 surface is coated with the resist (photosensitive agent).

[0196]

In the embodiment, of the lens elements referred to above, a plurality of lens elements are respectively capable of moving independently. For example, the lens

10 element 70a arranged topmost and closest to the reticle stage RST is held by a ring-shaped supporting member 72, and this ring-shaped supporting member 72 is supported at three points by expandable driving elements such as piezo elements 74a, 74b, and 74c (74c in depth of the drawing

15 is not shown in Fig. 1), and is also connected to the barrel portion 76. The three points on the periphery of the lens element 70a is movable independently in the optical axis direction AX of the projection optical system PL by the driving elements 74a, 74b, and 74c. That

20 is, translation operation of the lens element 70a can be performed along the optical axis AX in accordance with the deviation amount of the driving elements 74a, 74b, and 74c, as well as tilt operation of the lens element 70a in respect to the plane perpendicular to the optical axis AX. And the voltage provided to the driving elements

25 74a, 74b, and 74c is controlled by the image forming characteristics correction controller 78 based on

instructions from the main controller 50, and thus the deviation amount of the driving elements 74a, 74b, and 74c is controlled. Also, in Fig. 1, the optical axis AX of the projection optical system PL refers to the optical axis of the lens element 70b and the other lens elements (omitted in Fig. 1) fixed to the barrel portion 76.

[0197]

In addition, in the embodiment, the relation between the vertical movement amount of the lens element 70a and the variation in magnification (or in distortion) are obtained in advance by experiment. The relation is stored in a memory within the main controller 50, and the magnification (or distortion) correction is performed by calculating the vertical movement amount of the lens element 70a from the magnification (or distortion) corrected by the main controller 50 on correction, and by providing instructions to the image forming characteristics correction controller 78 to drive the driving elements 74a, 74b, and 74c to correct the magnification (or distortion). Further, optical calculation values can be used in the relation between the vertical movement amount of the lens element 70a and the variation in magnification. In this case, the experimental process to obtain the relation between the vertical movement amount of the lens element 70a and the variation in magnification can be omitted.

[0198]

As is described earlier, the lens element 70a closest to the reticle R is movable. The lens element 70a is selected, because the influence on the magnification and distortion characteristics is greater compared with the other lens elements, however, any lens element may be arranged movable alternately of the lens element 70a to adjust the interval between lenses, if identical conditions can be satisfied.

[0199]

Also, by moving at least one optical element besides the lens element 70a, other optical properties such as the field curvature, astigmatism, coma, and spherical aberration can be adjusted. Moreover, a sealed chamber may be arranged in between specific lens elements near the center in the optical axis direction of the projection optical system PL, and an image forming characteristics correction mechanism can be arranged to adjust the magnification of the projection optical system PL by adjusting the pressure of the gas inside the sealed chamber with a pressure adjustment mechanism such as a bellows pump. Or, alternately, for example, an aspherical lens may be used as a part of the lens element structuring the projection optical system PL, and the aspherical lens may be rotated. In this case, correction of the so-called rhombic distortion becomes possible. Or, the image forming characteristics correction mechanism may have the structure of a plane-parallel plate arranged

within the projection optical system PL, which can be tilted and rotated.

[0200]

Furthermore, in the case of using the laser beam with the wavelength of 193m as the exposure light IL, materials such as synthetic quartz and fluorite can be used for each lens element (and the plane-parallel plate) structuring the projection optical system PL. In the case of using the laser beam with the wavelength of 157nm, however, only fluorite is used as the material for the lenses and the like.

[0201]

In addition, in the embodiment, an atmospheric pressure sensor 77 is arranged to measure the atmospheric pressure in the chamber 11. The measurement values of the atmospheric pressure sensor 77 is sent to the main controller 50, and the main controller 50 calculates the change in pressure from the standard atmospheric pressure as well as calculate the atmospheric change of image forming characteristics in the projection optical system PL, based on the measurement values of the atmospheric pressure sensor 77. And, the main controller 50 gives instructions to the image forming characteristics correction controller 78 in consideration of this atmospheric variation, and corrects the image forming characteristics of the projection optical system PL.

[0202]

The change of oscillation wavelength referred to above, is achieved easily, by the laser controller 16B positively controlling the temperature of the etalon element making up the beam monitor mechanism 164 to change the set wavelength (target wavelength), which coincides with the resonance wavelength (detection reference wavelength) maximizing the transmittance of the etalon element, and also by feedback control of the temperature of the DFB semiconductor laser 160A to make the oscillation wavelength of the DFB semiconductor laser 160A coincide with the changed set wavelength, based on instructions from the main controller 50.

[0203]

Since the calculation method of the atmospheric pressure variation, the illumination variation, and the like performed by the main controller 50 is disclosed in detail, for example, in Japanese Patent Laid Open No. 09-213619 and is well acknowledged, a detailed description will therefore be omitted.

[0204]

The XY stage 14 is driven two-dimensionally, in the Y direction, which is the scanning direction, and in the X direction, which is perpendicular to the Y direction (the direction perpendicular to the page surface of Fig. 1), by the wafer stage driving portion 56. The Z tilt stage 58 is mounted on the XY stage 14, and on the Z tilt stage 58, the wafer W is held via a wafer holder 61 (not shown

in Figs.) by vacuum chucking and the like. The Z tilt stage 58 has the function of adjusting the position of the wafer W in the Z direction by for example, three actuators (piezo elements or voice coil motors), and also the function of adjusting the tilting angle of the wafer W in respect to the XY plane (image plane of the projection optical system PL). In addition, the position of the XY stage 14 is measured via the movable mirror 52W fixed on the Z tilt stage 58 by the laser interferometer 54W, which is externally arranged, and the measurement values of the laser interferometer 54W is sent to the main controller 50.

[0205]

As the movable mirror, in actual, an X movable mirror that has a reflection plane perpendicular to the X-axis and a Y movable mirror that has a reflection plane perpendicular to the Y-axis are arranged, and in correspondence with these mirrors, interferometers for an X-axis position measurement, Y-axis position measurement, and rotation (including yawing amount, pitching amount, and rolling amount) measurement are respectively arranged. In Fig. 1, however, these are representatively shown as the movable mirror 52W and the laser interferometer 54W.

[0206]

In addition, on the Z tilt stage 58 close to the wafer W, an irradiation amount monitor 59, which has a photo-detecting surface arranged at the same height as

that of the exposure surface on the wafer W, is arranged

to detect the light amount of the exposure light IL that

has passed through the projection optical system PL. The

irradiation amount monitor 59 has a housing that is one

5   size larger than the exposure area 42W, extends in the X

direction, and is rectangular in a planar view. And in

the center portion of this housing, an opening is formed,

which has a slit-shape almost identical to the exposure

area 42W. This opening is actually made by removing a

10   portion of a light shielding film formed on the upper

surface of the photo-detection glass made of materials

such as synthetic quartz, which forms the ceiling surface

of the housing. And, immediately below the opening via

the lens, an optical sensor having a photodetection

15   element such as the silicon PIN type photodiode is

arranged.

[0207]

The irradiation amount monitor 59 is used to measure

the intensity of the exposure light IL irradiated on the

20   exposure area 42W. The light amount signals according to

the amount of light received by the photodetection

element structuring the irradiation amount monitor 59 is

sent to the main controller 50.

[0208]

25   The optical sensor does not necessarily have to be

arranged within the Z tilt stage 58, and it is a matter

of course that the optical sensor may be arranged

exterior to the Z tilt stage 58. In this case, the illumination beam relayed by the relay optical system may be guided to the optical sensor via an optical fiber or the like.

5   **[0209]**

On the Z tilt stage 58, the fiducial mark plate FM used when performing operations such as reticle alignment, which will be described later, is arranged. The fiducial mark plate FM is arranged so that the height of the surface is almost the same as that of the surface of the wafer W. On the surface of the fiducial mark plate FM, fiducial marks for reticle alignment, baseline measurement, and the like, are formed.

[0210]

15   Also, it is omitted in Fig. 1 to avoid complication in the drawing, in actual, the exposure apparatus 10 comprises a reticle alignment system to perform reticle alignment.

[0211]

20   When alignment is performed on the reticle R, first of all, the main controller 50 drives the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the fiducial mark for reticle alignment on the fiducial mark plate FM is set within the exposure area 42W having a rectangular shape and the positional relationship between the reticle R and the Z tilt stage 58 is set so

that the reticle mark image on the reticle R almost overlaps the fiducial mark. In this state, the main controller 50 picks up the image of both marks using the reticle alignment system, processes the pick-up signals,

5   and calculates the positional shift amount of the projected image of the reticle mark in respect to the corresponding fiducial mark in the X direction and the Y direction.

[0212]

10 In addition, it is also possible to obtain the focus offset and leveling offset (the focal position of the projection optical system PL, image plane tilt, and the like) based on information on contrast, which is included in the detection signals (picture signals) of the

15 projected image of the fiducial marks obtained as a consequence of the reticle alignment described above.

[0213]

Also, in the embodiment, when the reticle alignment is performed, the main controller 50 also performs

20 baseline measurement of the off-axis alignment sensor on the wafer side (not shown in Figs.) arranged on the side surface of the projection optical system PL. That is, on the fiducial mark plate FM, fiducial marks for baseline measurement that are arranged in a predetermined

25 positional relationship in respect to the fiducial marks for reticle alignment are formed. And when the positional shift amount of the reticle mark is measured via the

reticle alignment system, the baseline amount of the alignment sensor, in other words, the positional relationship between the reticle projection position and the alignment sensor, is measured by measuring the

5 positional shift of the fiducial marks for baseline measurement in respect to the detection center of the alignment sensor via the alignment sensor on the wafer side.

[0214]

10 Furthermore, as is shown in Fig. 1, with the exposure apparatus 10 in the embodiment, it has a light source which on/off is controlled by the main controller 50, and a multiple focal position detection system (a focus sensor) based on the oblique incident method is arranged,

15 consisting of an irradiation optical system 60a which irradiates light from an incident direction in respect to the optical axis AX to form multiple pinhole or slit images toward the image forming plane of the projection optical system PL, and of an photodetection optical

20 system 60b which photo-detects the light reflected off the surface of the wafer W. By controlling the tilt of the plane-parallel plate arranged within the photodetection optical system 60b (not shown in Figs.) in respect to the optical axis of the reflected light, the

25 main controller 50 provides an offset corresponding to the focal change of the projection optical system PL to the focal detection system (60a, 60b) and performs

calibration. With this operation, the image plane of the projection optical system PL within the exposure area 42W coincides with the surface of the wafer W within the range (width) of the depth of focus. Details on the structure of the multiple focal position detection system (a focus sensor) similar to the one used in the embodiment, are disclosed in, for example, Japanese Patent Laid Open No. 06-283403.

[0215]

The main controller 50 performs automatic focusing and automatic leveling by controlling the Z position of the Z tilt stage 58 via the driving system (not shown in Figs.) so that the defocus becomes zero, based on the defocus signals such as the S-curve signals from the photodetection optical system 60b.

[0216]

The reason for arranging the plane-parallel plate within the photodetection optical system 60b to provide an offset to the focal detection system (60a, 60b) is, for example, that when the lens element 70a is vertically moved for magnification correction the focus also changes, and when the projection optical system PL absorbs the exposure light IL the position of the image forming plane changes with the change in the image forming characteristics of the projection optical system PL, and accordingly, it is necessary in such cases to make the focusing position of the focal detection system coincide

with the position of the image forming plane of the projection optical system PL by providing an offset to the focal detection system. Therefore, in the embodiment, the relationship between the vertical movement amount of

5 the lens element 70a and the focus variation is also obtained in advance by experiment, and stored in a memory within the main controller 50. Calculated values may be used for the relationship between the vertical movement amount of the lens element 70a and the focus variation.

10 And, as for the automatic leveling, it may be performed only in the non-scanning direction, which is perpendicular to the scanning direction, without being performed in the scanning direction.

[0217]

15 The main controller 50 is structured including a so-called microcomputer (or workstation) made up of components such as a CPU (central processing unit), a ROM (Read Only Memory), a RAM (Random Access Memory), and the like. Other than performing various controls described so

20 far, the main controller 50 controls, for example, the synchronous scanning of the reticle R and the wafer W, the stepping operation of the wafer W, the exposure timing, and the like so that the exposure operation is performed accurately. In addition, in the embodiment, the

25 main controller 50 has control over the whole apparatus, besides controls such as controlling the exposure amount on scanning exposure as will be described later, and

calculating the variation amount of the image forming characteristics of the projection optical system PL and adjusting the image forming characteristics of the projection optical system PL based on the calculation via

5   the image forming characteristics correction controller 78.

[0218]

To be more precise, for example, on scanning exposure, the main controller 50 respectively controls the position

10   and velocity of the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the wafer W is scanned via the XY stage 14 at the velocity $V_W = \beta \cdot V$ (β is the projection magnification from the reticle R to the wafer

15   W) in the -Y direction (or +Y direction) in respect to the exposure area 42W, in synchronous with the reticle R scanned via the reticle stage RST at the velocity $V_R = V$ in the +Y direction (or -Y direction), based on the measurement values of the laser interferometers 54R and

20   54W. Also, when performing stepping operations, the main controller 50 controls the position of the XY stage 14 via the wafer stage driving portion 56, based on the measurement values of the laser interferometer 54W.

[0219]

25   The exposure sequence of the exposure apparatus 10 in the embodiment will be described next, when exposure on predetermined slices (N slices) of wafers W is performed

to transfer the reticle pattern onto the wafer W, while
mainly referring to the controls performed by the main
controller 50.

[0220]

5   The premise is as follows:

① A shot map data (data deciding the exposure sequence
of each shot area and the scanning direction) is made and
stored in the memory 51 (refer to Fig. 1), based on
necessary data such as the shot arrangement, size of shot,

10   and exposure sequence of each shot, which are input by
the operator through an input/output device 62 (refer to
Fig. 1) such as a console.

② In addition, the output of the integrator sensor 46 is
calibrated in advance in respect to the output of the

15   reference illuminometer (not shown in Figs.) that is
arranged on the Z tilt stage 58 at the same height as of
the image plane (that is, the surface of the wafer W).
The calibration of the integrator sensor 46, in this case,
means to obtain the conversion coefficient (or conversion

20   function) to convert the output of the integrator sensor
46 to the exposure amount on the image plane. By using
this conversion coefficient, measuring the exposure
amount (energy) indirectly provided on the image plane by
the output of the integrator sensor 46 becomes possible.

25   ③ In addition, the output of: the energy monitor within
the beam monitor mechanism 164; the photoconversion
elements 180, 181 within the light amplifying portion

161; and the photoconversion element 182 within the wavelength conversion portion 163, and the like are calibrated in respect to the output of the integrator sensor 46 that has already been calibrated. The relative

5   coefficient of the output of the respective sensors in respect to the output of the integrator sensor 46 is also obtained in advance, and stored in the memory 51.

④   Furthermore, in respect to the output of the integrator sensor 46 which has completed calibration, the

10   output of the reflection light monitor 47 is calibrated. The relative coefficient of the output of the reflection light monitor 47 in respect to the output of the integrator sensor 46 is obtained in advance, and stored in the memory 51.

15   **[0221]**

First of all, the operator inputs the exposure conditions including the illumination conditions (the numerical aperture of the projection optical system, the shape of the secondary light source (the type of aperture

20   stop 24), the coherence factor σ and the type of reticle pattern (such as contact hole, line and space), the type of reticle (such as phase contrast reticle, half-tone reticle), and the minimum line width or the exposure amount permissible error) from the input/output device 62

25   (refer to Fig. 1) such as the console. According to the input, the main controller 50 sets the aperture stop (not shown in Figs.) of the projection optical system PL,

selects and sets the aperture stop of the illumination system aperture stop plate 24, and sets the target exposure amount (which corresponds to the set light amount) in accordance with the resist sensitivity, and the like. While these are being performed, at the same time, the main controller 50 selects the channels to be turned on/off at the bundle-fiber 173 output so that the light amount emitted from the light source unit 16 in order to obtain the target exposure amount almost coincides with the set light amount, and gives instructions to the light amount controller to select the specific channels. With this operation, on scanning exposure, which will be described later, the light amount controller 16C performs the on/off operation of the fiber amplifier 171_n of each channel almost simultaneously with the emission of the laser light source 160A, based on the first function in accordance with the selection instructions. Thus, rough adjustment of the exposure amount is performed.

[0222]

Next, the main controller 50 loads the reticle R subject to exposure on the reticle stage RST, using the reticle loader (not shown in Figs.).

[0223]

Then, the reticle alignment described earlier is performed, using the reticle alignment system, as well as the baseline measurement.

[0224]

And then, the main controller 50 instructs the wafer carriage system (not shown in Figs.) to exchange the wafer W. By the instructions, the wafer is exchanged (or

5   simply loaded when there are no wafers on the stage) by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14. When this is completed, a series of operations in the alignment process are performed, such as the so-called

10   search alignment, and fine alignment (EGA and the like). Since the wafer exchange and the wafer alignment are performed likewise, as is performed with the well-acknowledged exposure apparatus, more detailed description is omitted here.

15   **[0225]**

Next, based on the above alignment results and the shot map data, the reticle pattern is transferred onto a plurality of shot areas on the wafer W based on the step-and-scan method by repeatedly performing the operation of

20   moving the wafer W to the starting position for scanning to expose each shot area on the wafer W and the scanning exposure operation. During this scanning exposure, in order to provide the target exposure amount to the wafer W, which is decided in accordance with exposure

25   conditions and the resist sensitivity, the main controller 50 gives instructions to the light amount controller 16C while monitoring the output of the

integrator sensor 46. And according to the instructions, in addition to the rough adjustment of the exposure amount based on the first function, the light amount controller 16C controls the frequency and the peak power

5 of the laser beam (pulse ultraviolet light) from the light source unit 16 based on the second and third functions, thus performs fine adjustment of the exposure amount.

[0226]

10 In addition, the main controller 50 controls the illumination system aperture stop plate 24 via the driving unit 40, and furthermore, controls the opening/closing of the movable reticle blind 30B in synchronous with the operation information of the stage

15 system.

[0227]

When exposure on the first wafer W is completed, the main controller 50 instructs the wafer carriage system (not shown in Figs.) to exchange the wafer W. Wafer

20 exchange is thus performed, by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14, and after the wafer exchange is completed, search alignment and fine alignment is performed likewise as is described above to the wafer

25 that has been exchanged. In addition, in this case, the main controller 50 calculates the irradiation change of the image forming characteristics (including the change

in focus) of the projection optical system PL from the start of exposure on the first wafer W, based on the measurement values of the integrator sensor 46 and the reflection light monitor 47. The main controller 50 then

5   provides instruction values to the image forming characteristics correction controller 78 to correct the irradiation change, as well as provides an offset to the photodetection optical system 60b. Also, the main controller 50 calculates the atmospheric pressure change

10   of the image forming characteristics of the projection optical system PL based on the measurement values of the atmospheric pressure sensor 77, and provides instruction values to the image forming characteristics correction controller 78 to correct the irradiation change, as well

15   as provides an offset to the photodetection optical system 60b.

[0228]

And, in the same manner as described earlier, the reticle pattern is transferred onto the plurality of shot

20   areas on the wafer W based on the step-and-scan method.

[0229]

In this case, the rough adjustment of the exposure amount (light amount) described earlier may be precisely controlled in the accuracy of 1% and under to the

25   exposure amount set value, by performing test emission prior to the actual exposure.

[0230]

The dynamic range of the rough adjustment of the exposure amount in the embodiment can be set within the range of 1 - 1/128. The dynamic range normally required, however, is around 1 - 1/7 in typical, therefore, the number of channels (the number of optical fibers) which light output should be turned on may be controlled in between 128 - 18. In this manner, in the embodiment, rough adjustment of the exposure amount in line with the difference of the resist sensitivity and the like of each wafer can be accurately performed by the exposure amount control individually turning on/off the light output of each channel.

[0231]

Accordingly, with the embodiment, the rough energy adjuster such as the ND filter used in the conventional excimer laser exposure apparatus is not necessary.

[0232]

In addition, since the light amount control based on the second and third function by the light amount controller 16C has the features of quick control velocity and high control accuracy, it is possible to satisfy the following control requirements required in the current exposure apparatus without fail.

[0233]

That is, the light amount control satisfies all of: the dynamic range being around ±10% of the set exposure amount, which is a requirement for exposure amount

control correcting the process variation of each shot

area (chip) on the same wafer caused due to uneven resist

film thickness within the same wafer; controlling the

light amount to the set value within around 100ms, which

5   is the stepping time in between shots; control accuracy

of around ±1% of the set exposure amount; setting the

light amount to ±0.2% of the set exposure amount within

20msec, which is the typical exposure time for one shot

area as the exposure accuracy, being a requirement for

10   exposure control to achieve line width uniformity within

a shot area; and the control velocity of around 1ms.

[0234]

Accordingly, for light amount control, the light

amount controller 16C only has to perform light amount

15   control based on at least either the second function or

the third function.

[0235]

In addition, with the scanning exposure apparatus

that has a laser light source (pulse light source) as in

20   the exposure apparatus 10 of the embodiment, when the

scanning velocity of the wafer W is V_W, the width of the

slit shaped exposure area 42W on the wafer W in the

scanning direction (slit width) is D, and the pulse

repetition frequency of the laser light source is F, the

25   distance in which the wafer W moves in between pulse

emission is V_W/F, thus the number of pulse (the number of

exposure pulse) N of the exposure light IL to be

irradiated at one point on the wafer W is expressed as in the following equation (3).

[0236]

$$N=D/(V_W/F) \qquad \cdots\cdots (3)$$

5 **[0237]**

When the pulse energy is expressed as P, the energy that is to be provided at one point on the wafer W for a unit time is expressed as in the following equation (4).

[0238]

10 $$E=NP=ND/(V_W/F) \qquad \cdots\cdots (4)$$

[0239]

Accordingly, with the scanning exposure apparatus, exposure amount control is possible by controlling either the slit width D, the scanning velocity V_W, the pulse

15 repetition frequency F of the laser light source, or the pulse energy P. Due to the problem of response velocity, since it is difficult to adjust the slit width D during scanning exposure, either the scanning velocity V_W, the pulse repetition frequency F of the laser light source,

20 or the pulse energy P may be adjusted.

[0240]

Therefore, with the exposure apparatus 10 in the embodiment, as a matter of course, the exposure amount control can be performed by combining the light amount

25 control based on either the second or third function by the light amount controller 16C and the scanning velocity.

[0241]

For example, the exposure conditions of the wafer W is changed in accordance with the reticle pattern to be transferred onto the wafer W, such as changing the intensity distribution of the illumination light (that is,

5 the shape and size of the secondary light source) on the pupil surface of the illumination optical system, or inserting/removing the optical filter which shields the circular area having the optical axis as its center around the pupil surface of the projection optical system

10 PL. The illuminance on the wafer W changes by these changes in exposure conditions, however, the illuminance on the wafer W also changes with the change in the reticle pattern. This is due to the difference in the occupied area by the shielding area (or the transmitting

15 area) of the pattern. Therefore, when the illuminance changes due to the change of at least either the exposure conditions or the reticle pattern, it is preferable to control at least either the frequency or the peak power referred to above so as to provide the suitable exposure

20 amount to the wafer (resist). On this control, in addition to adjusting at least either the frequency or the peak power, the scanning velocity of the reticle and the wafer may also be adjusted.

[0242]

25 As is described above, with the light source unit 16 related to the embodiment, a laser beam with a single wavelength generated in the light generating portion 160

passes through the delay portion 167 and proceeds toward each of 128 optical fibers (optical paths 172_n) in total arranged in parallel on the output side, while the light amount controller 16C controls the light amount emitted

5 from the fiber group (the entire optical path 172_n) by individually turning on/off light output from each optical path 172_n. In this manner, in the embodiment, the amount of light emitted from the entire optical path 172_n can be controlled by a simple method of individually

10 turning on/off the light output from each optical path 172_n.

[0243]

Further, in this case, because light amount control in 128 stages, which is proportional to the number of

15 optical paths, becomes possible, a wide dynamic range can be easily achieved. Also, since various performances of respective optical paths are almost same, the same light amount can be output from each optical path. Consequently, the light amount control in 128 stages in accordance with

20 the number of the optical paths can be performed with good linearity. In this case, the light amount can be controlled with the precision of 1% and under.

[0244]

Further, with light source unit 16 as described above,

25 the rough energy adjuster such as the ND filter will not be necessary, therefore, problems such as deterioration in light amount control performance due to the durability

of the filter or the temporal change in transmittance can be remedied.

[0245]

In addition, an output end of each of the fiber

5   amplifier 171_n making up each optical path is bundled so as to structure the bundle-fiber 173, and the diameter of the entire bundle fiber 173 is 2mm and under. Therefore, a compact optical element can be used as an optical element structuring the quarter-wave plate 162 arranged

10   on the output side and the wavelength conversion portion 163, such as a nonlinear optical crystal.

[0246]

Further, the fiber amplifiers 168_n and 171_n are arranged on a part of each optical path 172_n, and the

15   light amount controller 16C performs the on/off operation of the light output of each optical path 172_n by switching the intensity of pumped light from the pumping semiconductor laser 174 of the fiber amplifier 171_n arranged at the final stage. Therefore, since the light

20   incident on the optical path 172_n from the fiber amplifier 168_n and 171_n can be amplified, and the intensity level of the pumped light supplied to the fbier amplifier 171_n arranged on the optical path 172_n which output has been decided to be turned off is set at a low level (including

25   zero), energy saving becomes possible. In addition, since the on/ff operation of the light output is performed by switching the light intensity of the pumped light from

the pumping semiconductor laser 174 of the fiber amplifier, the on/off operation of the light output becomes possible within a shorter period of time, compared with the case of using shutters and the like.

[0247]

Further, since the on/off operation of the light output from optical path 172_n is performed by switching the intensity of pumped light from the pumping semiconductor laser 174 of the fiber amplifier 171_n arranged at a final stage, the adverse effect of the ASE, which is a problem when switching the intensity of the pumped light from the pumping light source of fiber amplifiers other than the fiber amplifier arranged at the final stage, can be avoided. Also, since the fiber amplifier 171_n requires the highest intensity of pumped light, the effect on energy saving becomes greater when the light output from the fiber amplifier 171_n is turned off.

[0248]

In addition, since the fiber amplifier 171_n arranged most downstream directly before the light output has the larger mode field diameter, when compared with the fiber amplifier 168_n, broadening of the spectral width of the amplified light can be avoided, due to the nonlinear effect in the optical fiber.

[0249]

In addition, the first output intensity map

corresponding to an on/off state of light output from the optical path 172_n is stored in advance in the memory unit 51, and the light amount controller 16C individually turns on/off light output from each optical path 172_n

5   based on the first output intensity map and a predetermined set light amount. Therefore, even if the output of each optical path 172_n is dispersed, the light output of the entire optical path can be made to almost coincide with the set light amount, and it is also

10 possible to structure the optical path using structuring materials which performances differ. That is, it becomes possible to use the optical fibers and the like which performances (including a fiber diameter and the like) differ.

15   **[0250]**

    The first output intensity map is made based on dispersion of light output from each optical path actually measured in advance, and therefore the light output of the entire optical path can be made to coincide

20 with the set light amount without fail.

        [0251]

    In addition, the light source unit 16 of the embodiment comprises the wavelength conversion portion 163 which converts the wavelength of light emitted from

25 each optical path 172_n, and the output of the wavelength conversion portion 163 is in proportion to the number of the optical paths which light output is turned on (the

number of channels). Accordingly, in the case the performances of the optical paths are almost same, the same amount of light can be emitted from each optical path 172_n, and as a consequence, the light amount can be

5 controlled with good linearity.

[0252]

In addition, because the first output intensity map is made with further consideration on output dispersion due to dispersion in wavelength conversion efficiency

10 which corresponds to each optical path output measured in advance, even if the wavelength conversion efficiency is dispersed with respect to the light output from each optical path, the light amount of the output light can be controlled to the set light amount.

15 **[0253]**

The light source unit 16 related to the embodiment comprises a delay portion 167 which individually delays light output from the plurality of optical paths respectively so as to stagger the light output temporally.

20 Thus, since the light is not emitted from each optical path at the same time, consequently, the light output from the light source unit 16 is not emitted at the same time while being an extremely narrow banded light having a single wavelength, and the spatial coherency between

25 outputs from respective channels can be reduced.

[0254]

With the light source unit 16 related to the

embodiment, by controlling the frequency of the pulse light emitted from the EOM160C with the light amount controller 16C, the light amount of the emitted light from the fiber amplifier structuring the light amplifying

5   portion 161 can be made to coincide with the set light amount (target light amount). With the light amount adjustment by controlling the frequency of the pulse light (the number of pulse per unit time), a faster and finer light amount adjustment becomes possible compared

10   with the individual on/off operation of the light output from the light path as described above, and if the set light amount is within a predetermined range the light amount can be made to almost coincide with the set light amount, whatever value the set light amount may be.   In

15   addition, the linearity between the light output and the control amount is favorable.

     [0255]

     The second output intensity map based on output intensity of the light amplifying portion 161

20   corresponding to a frequency of the pulse light entering the light amplifying portion 161 is stored in the memory unit 51, and the light amount controller 16C controls the frequency of the pulse light emitted from the EOM160C based on the second output intensity map and a

25   predetermined set light amount. Therefore, light amount control with high precision is possible, without being affected by the change in the peak power of the pulse

output from the light amplifying portion 161 due to the incident light intensity dependence which the gain of the fiber amplifier structuring the light amplifying portion 161 has.

5   **[0256]**

With the light source unit 16 related to the embodiment, by controlling the peak power of the pulse light emitted from the EOM160C with the light amount controller 16C, the light amount of the emitted light
10   from the fiber amplifier structuring the light amplifying portion 161 can be made to coincide with the set light amount (target light amount). With the light amount adjustment by controlling the peak power of the pulse light, a faster and finer light amount adjustment becomes
15   possible compared with the individual on/off operation of the light output from the light path as described above, and if the set light amount is within a predetermined range the light amount can be made to almost coincide with the set light amount, whatever value the set light
20   amount may be.

[0257]

The third output intensity map based on output intensity of the light amplifying portion 161 corresponding to intensity of the pulse light entering
25   the light amplifying portion 161 is stored in the memory unit 51, and the light amount controller 16C controls the peak power of the pulse light emitted from the EOM160C

based on the third output intensity map and a predetermined set light amount. Therefore, light amount control with high precision is possible, without being affected by the change in the peak power of the pulse output from the light amplifying portion 161 due to the incident light intensity dependence which the gain of the fiber amplifier structuring the light amplifying portion 161 has.

[0258]

Further, the light amount controller 16C of the embodiment has the functions of light amount control by individually performing on/off operation on the light output from the optical path (the first function), light amount control by controlling the frequency of the pulse light emitted from the EOM160C (the second function), and light amount control by controlling the peak power of the pulse light emitted from the EOM160C (the third function). Therefore, in addition to the sequential light amount control by individually performing on/off operation on the light output from the optical path 172_n based on the first function and at least either the second or third function, fine adjustment of the light amount at each stage becomes possible by controlling at least either the frequency or the peak power of the pulse light emitted from the EOM160C. As a consequence, continuous control of the light amount becomes possible, and if the set light amount is within a predetermined range the light amount

of the output light can be made to coincide with the set

light amount, whatever value the set light amount may be.

[0259]

In addition, since the light amount controller 16C

5   can further control the peak power in addition to the

frequency of the pulse light emitted from the EOM160C by

the second function and the third function, light amount

control with high precision is possible even in the case

when there is a change in the peak power of the pulse

10 light.

[0260]

However, the present invention is not limited to this,

and the light amount controller structuring the light

source unit related to the present invention may only

15 have at least one of the first to third functions

described above.

[0261]

Further, with the exposure apparatus 10 related to

the embodiment, the illumination optical system 12

20 illuminates a reticle R with an ultraviolet light

(wavelength: 193nm or 157nm), as an illumination light

for exposure, emitted from the wavelength conversion

portion 163 of the light source unit 16, and a pattern

formed on the reticle R is transferred onto the wafer W.

25 In this case, the light source unit 16 can perform the

light amount control of the ultraviolet light irradiated

on the reticle R depending on the requirements, and

consequently the exposure amount control required can be performed.

[0262]

With the exposure apparatus 10, the light generating portion 160 generates a pulse light by converting light with a single wavelength generated in the light source 160A with the EOM160C, and the pulse light is amplified by the light amplifying portion 161 including the fiber amplifier. And when the main controller 50 irradiates the amplified pulse light on the reticle R and the wafer W is exposed via the reticle, the light amount controller 16C controls either of the frequency or the peak power of the pulse light via the EOM160C according to a position of an area subject to exposure on the wafer, that is, a position on the wafer of each shot area or a position of an area illuminated by a slit shaped illumination area within each shot area. With this operation, the light amount irradiated on the reticle R, and furthermore, the exposure amount on the wafer is controlled with high precision. Accordingly, an appropriate exposure amount control becomes possible at all times regardless of the position on the wafer of the area subject to exposure, and it becomes possible to transfer a pattern of the reticel R onto the wafer W with favorable accuracy. That is, correction of process variation in each shot area on the wafer and improvement in line width uniformity within each shot area becomes possible.

[0263]

With the exposure apparatus related to the embodiment, when the main controller 50 irradiates the amplified pulse light on the reticel R and the wafer W is exposed

5   via the reticel R, the light amount controller 16C controls the light amount of the pulse light emitted from the light amplifying portion 161 by individually turning on/off the light output from each optical path 172_n. With this operation, the light amount irradiated on the

10   reticle R, and furthermore, the exposure amount on the wafer is controlled step-by-step in a wide range. Accordingly, exposure amount control depending on the different resist sensitivity and the like of each wafer when repeatedly performs exposure on a plurality of

15   wafers becomes possible. Thus, it becomes possible to transfer a reticle pattern on the wafer with a required accuracy, without being affected by the resist sensitivity and the like.

[0264]

20   In the embodiment above, the case has been described when the on/off operation of the light output of each optical path (each channel) is performed, by switching the intensity of the pumped light of the fiber amplifier. The present invention, however, is not limited to this,

25   and for example, various cases may be considered such as a mechanical or an electrical shutter being arranged to cut off the light incident on each optical path, or a

mechanical or an electrical shutter being arranged so as to prevent the light from each optical path from being emitted.

[0265]

5 In addition, in the embodiment above, the case has been described when the optical path of the light amplifying portion 161 is 128 channels, however, the channel of the light amplifying portion may be only one channel. Even in such a case, the frequency control of 10 the pulse light emitted from the optical modulator such as the EOM, and light amount, exposure amount control by peak power control can be suitably applied.

[0266]

In the embodiment above, the number of fibers forming the 15 bundle-fiber is 128, however, the number may be any number, and the number can be determined depending on the product in which the light source unit related to the present invention is applied, such as, the specification (illuminance on the wafer) and optical properties 20 required in the exposure apparatus, that is, the transmittance of the illumination optical system and the projection optical system, the conversion efficiency of the wavelength conversion portion, and the output of the optical path. Furthermore, the wavelength of the 25 ultraviolet light is set almost the same as that of the ArF excimer laser or the F_2 laser in the embodiment above, however, the set wavelength may be of any wavelength, and

the oscillation wavelength of the laser light source 160A,
the structure of the wavelength conversion portion, and
the magnification of the harmonic wave may be decided
according to the set wavelength. As an example, the set
wavelength may be set in accordance with the design rule
(such as the line width and pitch) of the pattern to be
transferred onto the wafer, moreover, on deciding the set
wavelength, the exposure conditions and the type of
reticle (whether the reticle is the phase shift type or
not) previously referred to may be considered.

[0267]

In the embodiment above, to control the oscillation
wavelength of the laser light source 160A, the laser beam
is monitored by the beam monitor mechanism 164 arranged
immediately after the laser light source 160A. The
present invention, however, is not limited to this, and
as is shown in Fig. 5 in dotted lines, the laser beam may
be separated within the wavelength conversion portion 163
(or downstream in the wavelength conversion portion 163),
and may be monitored by the beam monitor mechanism 183,
which is similar to the beam monitor mechanism 164. And,
the main controller 50 detects whether the wavelength
conversion is performed accurately based on the
monitoring results of the beam monitor mechanism 183, and
based on the detection results may feedback control the
laser controller 16B. Naturally, the monitoring results
of both beam monitor mechanisms may be used to perform

oscillation wavelength control of the laser light source 160A.

[0268]

In addition, although it is not specifically referred

5   to in the description above, with the exposure apparatus which performs exposure using the wavelength of 193nm and under as in the embodiment, measures such as filling or creating a flow of clean air that has passed through a chemical filter, dry air, N_2 gas, or inert gas such as

10   helium, argon, or krypton in the passage of the exposure beam, or vacuuming the passage of the exposure beam, need to be taken.

[0269]

The exposure apparatus in the embodiment above is

15   made by assembling various subsystems including elements defined in the claims of the present application so as to keep a predetermined mechanical precision, electrical precision, and optical precision. In order to ensure these areas of precision, prior to and after the assembly,

20   adjustment is performed on various optical systems to attain a predetermined optical precision, adjustment is performed on various mechanical systems to attain a predetermined mechanical precision, and adjustment is performed on various electrical systems to attain a

25   predetermined electrical precision, respectively. The process of incorporating various subsystems into an exposure apparatus includes mechanical connection of

various subsystems, by wiring electrical circuits, piping pressure circuits, and the like. Obviously, before the process of incorporating various subsystems into an exposure apparatus, the process of assembling the

5 respective subsystems is performed. After the process of assembling various subsystems into the exposure apparatus is completed, total adjustment is performed to ensure preciseness in the overall exposure apparatus. The exposure apparatus is preferably made in a clean room in

10 which temperature, degree of cleanliness, and the like are controlled.

[0270]

Also, in the embodiment above, the case has been described when the light source unit is used in a

15 scanning exposure apparatus based on the step-and-scan method, however, the light source unit related to the present invention can be applied in units besides the exposure apparatus, for example, in a laser repair unit used to cut off a part of a circuit pattern (such as a

20 fuse) formed on a wafer. In addition, the light source unit in the present invention can also be applied to inspection units using visible light or infrared light. And in this case, there is no need to incorporate the wavelength conversion portion into the light source. That

25 is, the present invention is also effective with not only the ultraviolet laser unit, bus also with the laser unit that generates a fundamental wave in the visible light

region or the infrared light region having no wavelength

conversion portion. In addition, the present invention is

not limited to the scanning exposure apparatus based on

the step-and-scan method, and can be suitably applied to

5   the static exposure type, for example, to the exposure

apparatus based on the step-and-repeat method (such as

the stepper). Furthermore, the present invention can also

be applied to the exposure apparatus based on the step-

and-stitch method, to the mirror projection aligner, and

10   the like.

[0271]

The projection optical system and the illumination

optical system referred to above in the embodiment, are

mere examples, and it is a matter of course that the

15   present invention is not limited to these. For example,

the projection optical system is not limited to the

refraction optical system, and a reflection system made

up of only reflection optical elements or a reflection

refraction system (a catadioptric system) that is made up

20   of both the reflection optical elements and the

refraction optical elements may be employed. With the

exposure apparatus using vacuum ultraviolet light (VUV

light) having the wavelength of around 200 nm and under,

the use of the reflection refraction system can be

25   considered as the projection optical system. As the

projection optical system of the reflection/refraction

type, for example, a reflection/refraction system having

a beam splitter and concave mirror as reflection optical elements, which details are disclosed in, for example, Japanese Patent Laid Open No.08-171054 and Japanese Patent Laid Open No. 10-20195 can be used. Or, the

5 reflection/refraction system having a concave mirror and the like as reflection optical elements without using any beam splitter, which details are disclosed in, for example, Japanese Patent Laid Open No.08-334695 and Japanese Patent Laid Open No. 10-3039 can also be used.

10 **[0272]**

Besides the systems referred to above, the reflection/refraction system in which a plurality of refracting optical elements and two mirrors (a concave mirror serving as a main mirror, and a sub-mirror serving

15 as a back-mirror forming a reflection plane on the side opposite to the incident plane of a refracting element or a parallel flat plate) are arranged on the same axis, and an intermediate image of the reticle pattern formed by the plurality of refracting optical elements is re-formed

20 on the wafer by the main mirror and the sub-mirror, may be used. The details of this system is disclosed in, U.S. Patent No. 5,488,229, and the Japanese Patent Laid Open No. 10-104513. In this reflection/refraction system, the main mirror and the sub-mirror are arranged in succession

25 to the plurality of refracting optical elements, and the illumination light passes through a part of the main mirror and is reflected on the sub-mirror and then the

main mirror. It then further proceeds through a part of the sub-mirror and reaches the wafer.

[0273]

In addition, with the embodiment above, the fly-eye lens system is used as the optical integrator (homogenizer), however, instead of this arrangement, the rod integrator may be used. In the illumination optical system that uses the rod integrator, the rod integrator is arranged so that its outgoing surface is almost conjugate with the pattern surface of the reticle R, therefore, for example, the fixed reticle blind 30A and the movable reticle blind 30B may be arranged in the vicinity of the outgoing surface of the rod integrator.

[0274]

Of course, the present invention can be suitably applied to not only the exposure apparatus used to manufacture a semiconductor device, but also to the exposure apparatus used to manufacture a display including the liquid crystal display device that transfers the device pattern onto a glass plate, to the exposure apparatus used to manufacture a thin-film magnetic head that transfers the device pattern onto a ceramic wafer, and to the exposure apparatus used to manufacture a pick-up device (such as a CCD).

[0275]

<<Device Manufacturing Method>>

[0276]

A device manufacturing method using the exposure apparatus described above in a lithographic process will be described next.

[0277]

Fig. 7 is a flow chart showing an example of manufacturing a device (a semiconductor chip such as an IC or LSI, a liquid crystal panel, a CCD, a thin magnetic head, a micromachine, or the like). As shown in Fig. 7, in step 201 (design step), function/performance is designed for a device (e.g., circuit design for a semiconductor device) and a pattern to implement the function is designed. In step 202 (mask manufacturing step), a mask on which the designed circuit pattern is formed is manufactured. In step 203 (wafer manufacturing step), a wafer is manufactured by using a silicon material or the like.

[0278]

Next, in step 204 (wafer processing step), an actual circuit and the like is formed on the wafer by lithography or the like using the mask and wafer prepared in steps 201 to 203, as will be described later. In step 205 (device assembly step), a device is assembled using the wafer processed in step 204. Step 205 includes processes such as dicing, bonding, and packaging (chip encapsulation) depending on the requirements.

[0279]

Finally, in step 206 (inspection step), a test on the

operation of the device manufactured in step 205, durability test, and the like are performed. After these steps, the device is completed and shipped out.

[0280]

5   Fig. 8 is a flow chart showing a detailed example of step 204 described above in manufacturing the semiconductor device. Referring to Fig. 8, in step 211 (oxidation step), the surface of the wafer is oxidized. In step 212 (CVD step), an insulating film is formed on

10   the wafer surface. In step 213 (electrode formation step), an electrode is formed on the wafer by vapor deposition. In step 214 (ion implantation step), ions are implanted into the wafer. Steps 211 to 214 described above constitute a pre-process for the respective steps in the

15   wafer process and are selectively executed in accordance with the processing required in the respective steps.

[0281]

When the above pre-process is completed in the respective steps in the wafer process, a post-process is

20   executed as follows. In this post-process, first, in step 215 (resist formation step), the wafer is coated with a photosensitive agent. Next, as in step 216 (exposure step), the circuit pattern on the mask is transcribed onto the wafer using the exposure apparatus 10 described

25   above. Then, in step 217 (developing step), the exposed wafer is developed. In step 218 (etching step), an exposed member on a portion other than a portion where

the resist is left is removed by etching. Finally, in step 219 (resist removing step), the unnecessary resist after the etching is removed.

[0282]

5   By repeatedly performing these pre-process and post-process steps, multiple circuit patterns are formed on the wafer.

[0283]

As described above, according to the device
10   manufacturing method of the embodiment, the exposure apparatus 10 and the exposure method in the embodiment above is used in the exposure process (step 216). Therefore, by improving the exposure accuracy, a device with high integration can be manufactured with high yield.

15   **[0284]**

[EFFECT OF THE INVENTION]

As have been described above, with each invention according to Claims 1 to 27, there can be provided a light source unit which can perform light amount control
20   corresponding to requirements necessary for control.

[0285]

In addition, with each invention according to Claims 28 to 33, there can be provided an exposure apparatus which can easily perform required exposure amount control.

25   **[0286]**

In addition, with each invention according to Claims 34 to 36, there can be provided an exposure method in

which required exposure amount control can be easily performed.

[0287]

In addition, with each invention according to Claims 37 and 38, there can be provided a device manufacturing method which can improve the productivity of the microdevice with high integration.

[BRIEF DESCRIPTION OF THE DRAWING]

[FIG. 1]

Fig. 1 is a schematic view showing the configuration of the exposure apparatus of the embodiment in the present invention.

[FIG. 2]

Fig. 2 is a block diagram showing the internal structure of the light source unit in Fig. 1 with the main control unit.

[FIG. 3]

Fig. 3 is a schematic view showing the arrangement of the light amplifying portion in Fig. 2.

[FIG. 4]

Fig. 4 is a sectional view showing the bundle-fiber formed by bundling the output end of the fiber amplifiers arranged at a final stage that structure the light amplifying portion.

[FIG. 5]

Fig. 5 is a schematic view showing the fiber

amplifiers structuring the light amplifying portion in Fig. 2 and its neighboring portion, with a part of the wavelength conversion portion.

[FIG. 6]

5   Fig. 6(A) is a view showing an arrangement example of a wavelength conversion portion which generates an ultraviolet light having a wavelength of 193nm by converting the wavelength of a reference wave emitted from the output end of the bundle-fiber 173 that has the

10   wavelength of 1.544µm to an eighth-harmonic wave using the nonlinear optical crystal, and Fig. 6(B) is a view showing an arrangement example of a wavelength conversion portion which generates an ultraviolet light having a wavelength of 157nm by converting the wavelength of a

15   reference wave emitted from the output end of the bundle-fiber 173 that has the wavelength of 1.57µm to a tenth-harmonic wave using the nonlinear optical crystal.

[FIG. 7]

Fig. 7 is a flow chart explaining an embodiment of a

20   device manufacturing method according to the present invention.

[FIG. 8]

Fig. 8 is a flow chart showing the processing in step 204 in Fig. 7.

25

[DESCRIPTION OF REFERENCED LETTERS/NUMERALS]

10   Exposure apparatus

12	Illumination optical system
16	Light source unit
16C	Light amount controller
22	Fly-eye lens system (Optical integrator)
50	Main controller (Control unit)
51	Memory (Storage Unit)
160	Light generating portion
160A	DFB semiconductor laser (Light source)
160C	EOM (Optical modulator)
161	Light amplifying portion
163	Wavelength conversion portion
167	Delay portion
168_n	Fiber amplifier
171_n	Fiber amplifier
172_n	Optical path
173	Bundle-fiber (Fiber group)
174	Semiconductor laser (Light source for pumped light)
178	Semiconductor laser (Light source for pumped light)
R	Reticle (Mask)
W	Wafer (Substrate)

[DOCUMENT NAME] ABSTRACT

[ABSTRACT]

[PROBLEMS TO BE SOLVED]

To provide a light source unit which can perform
5   light amount control corresponding to necessary
requirements for control.

[SOLUTION]

The light source unit 16 comprises: a light
generating portion 160 which has a single wavelength
10   oscillation light source 160A and an optical modulator
160C converting light from the light source into a pulse
light and emitting the pulse light; a light amplifying
portion 161 made up of an optical fiber group that each
has a fiber amplifier to amplify the pulse light from the
15   optical modulator; and a light amount controller 16C. The
light amount controller 16C performs a step-by-step light
amount control by individually turning on/off the light
output of each fiber making up the optical fiber group,
and a light amount control of controlling at least either
20   of the frequency or the peak power of the emitted pulse
light of the optical modulator. Accordingly, in addition
to the step-by-step light amount control, fine adjustment
of the light amount in between the steps becomes possible
due to the control of at least either the frequency or
25   the peak power of the pulse light, and if the set light
amount is within a predetermined range, the light amount
can be made to coincide with any set light amount.
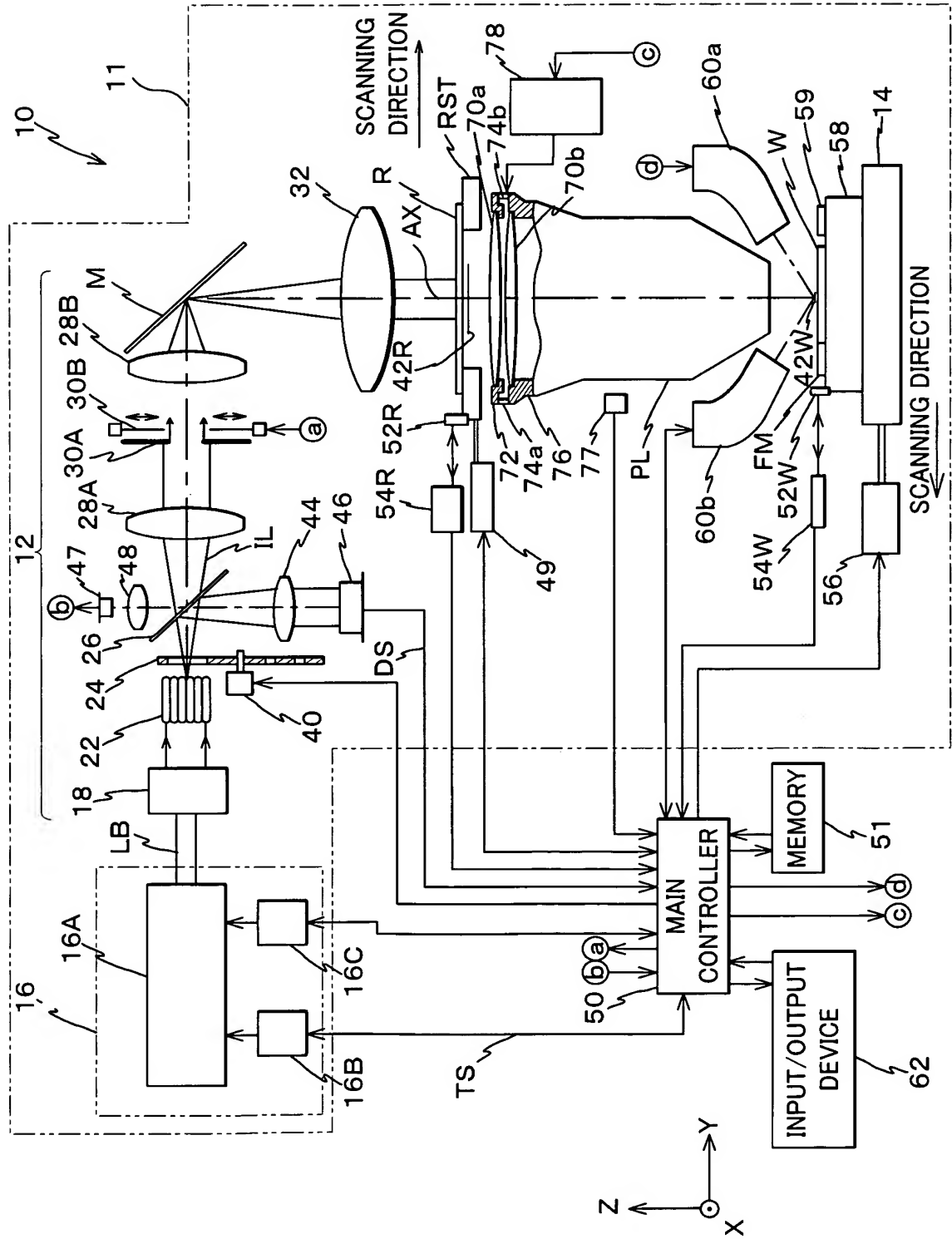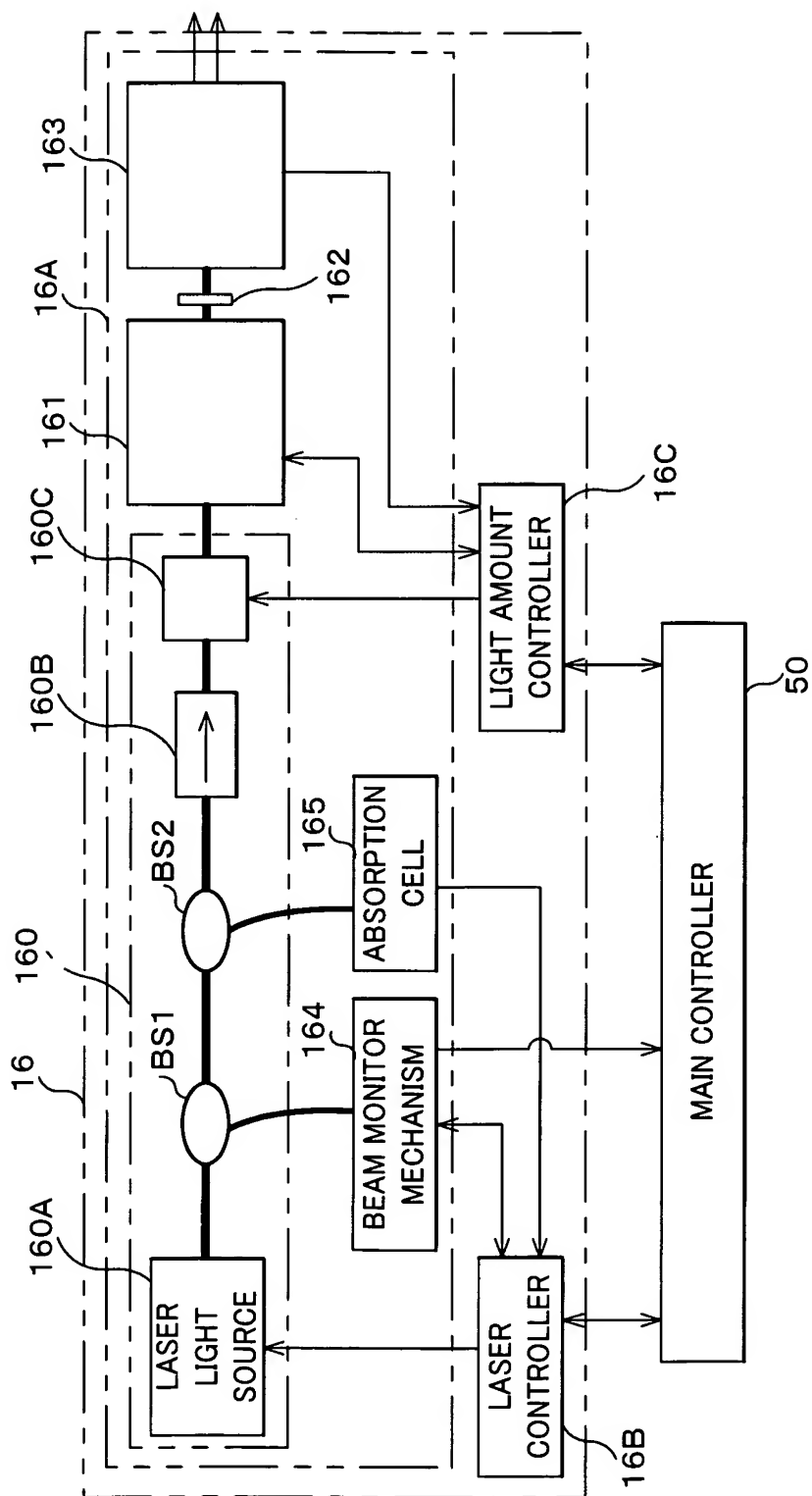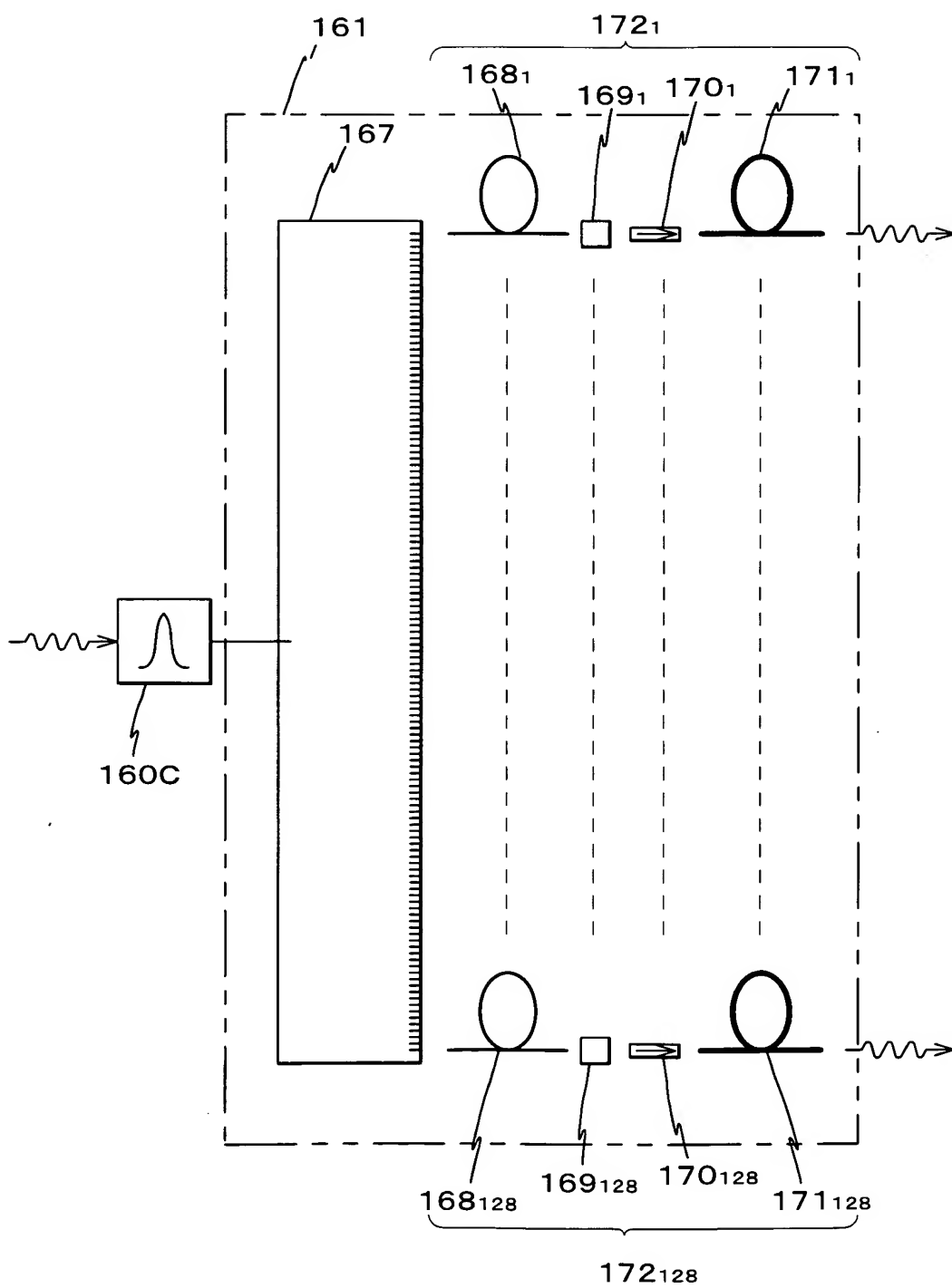
[DRAWING] FIG. 2
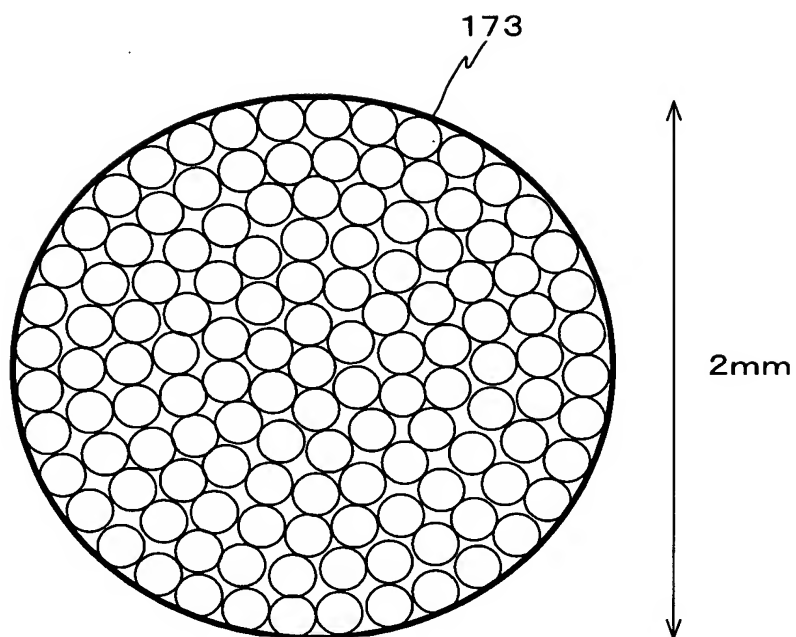
Fig. 1

Fig. 2

Fig. 3

Fig. 4

173

2mm

Fig. 5

Fig. 6

(A)

(B)

Fig. 7

201 → DESIGN (FUNCTION,PERFORMANCE, PATTERN)

203 → MANUFACTURE WAFER

202 → MANUFACTURE MASK

204 → PROCESS WAFER

205 → ASSEMBLE DEVICE

206 → INSPECT DEVICE

(SHIPMENT)

Fig. 8